FIELD CONTROL OF THE TEMPERATURE-TIME FACTOR IN HTST PASTEURIZATION

by

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FIELD CONTROL OF THE TEMPERATURE-TIME FACTOR IN HTST PASTEURIZATION

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ABSTRACT

For the study of phosphatase inactivation and cream volume impairment in the HTST region, the small commercial plate-type heat exchanger offers certain advantages over laboratory-size pasteurizers in that precise temperature, time and pressure measurements may be directly made at any desired point in the process. The experimental pasteurizer was of this type with a capacity of 1000 pounds/hour; temperatures were measured by indicating thermometers and thermocouples calibrated against an indicating thermometer graduated to 0.1°C. and certified by the National Research Council of Canada to 0.01°C.; milk times were calculated from water times measured by the salt-conductivity method; the thermal effect of heating-up and cooling was evaluated by Ball's method; the Sanders and Sager phosphatase test was the criterion of inactivation and the cream volume was measured in graduated cylinders with a change of 1 percent indicating impairment.

Assuming instantaneous heating-up and cooling, phosphatase was found to be inactivated at 160°F. in 16.8 seconds and the Z value (the temperature range in degrees during one logarithmic cycle of time) of the semi-logarithmic inactivation curve in the temperature range studied is 9.7°F. For

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For the study of phosphatase inactivation and cream volume impairment in the HTST region, the small commercial plate-type heat exchanger offers certain advantages over laboratory-size pasteurizers in that precise temperature, time and pressure measurements may be directly made at any desired point in the process. The experimental pasteurizer was of this type with a capacity of 1000 pounds/hour; temperatures were measured by indicating thermometers and thermocouples calibrated against an indicating thermometer graduated to 0.1°C. and certified by the National Research Council of Canada to 0.01°C.; milk times were calculated from water times measured by the salt-conductivity method; the thermal effect of heating-up and cooling was evaluated by Ball's method; the Sanders and Sager phosphatase test was the criterion of inactivation and the cream volume was measured in graduated cylinders with a change of 1 percent indicating impairment.

Assuming instantaneous heating-up and cooling, phosphatase was found to be inactivated at 160°F. in 16.8 seconds and the Z value (the temperature range in degrees during one logarithmic cycle of time) of the semi-logarithmic inactivation curve in the temperature range studied is 9.7°F. For

cream volume impairment only 15.0 seconds at 160°F. were required while the Z value of the semi-logarithmic destruction curve was 12.4°F. in the range studied.

Because of the complexity of the creaming problem the measurement of cream volume destruction does not provide a satisfactory criterion of HTST pasteurization. There are also objections to the use of the phosphatase test as the sole field control of HTST pasteurization. Thus there appears to be justification for a specified minimum holding time of 15 seconds at a minimum of 160°F.

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INTRODUCTION

Since the approval of the high-temperature short-time (usually abbreviated to HTST) method of milk pasteurization in Canada and the United States, the pasteurization standard for this method has been one or other of three standards; either a minimum temperature of 160°F. for a minimum holding time of 15 seconds, or 161°F. for 15 seconds, or 161°F. for 16 seconds. Since the fundamental purpose of milk pasteurization is to kill the pathogenic bacteria which may be suspended in the milk, it then becomes evident that the heat-resistant characteristics of the pathogenic organisms must be known. It is accepted that Mycobacterium tuberculosis is the most heat-resistant of the common milk pathogens. Thus, the immediate purpose of pasteurization is to kill the tubercle organism and this has become the universal basis of pasteurization. However, the heat-resistant characteristics of Mycobacterium tuberculosis in the region of HTST pasteurization are not definitely known. Thus, any estimation of the safety factor provided by HTST pasteurization is only an approximation and may or may not be close to that actually provided.

The real practical and immediate criterion of pasteurization today is inactivation of milk phosphatase. In practice this test is now being used extensively to control the minimum

pasteurization temperature-time combinations. The upper limits of the temperature-time combinations should be below the point at which the creaming properties of the unhomogenized milk begin to be significantly affected.

In this study it is proposed to investigate the feasibility of basing the field control of HTST pasteurization on the destruction of the milk phosphatase and the destruction of the creaming property of the milk when these criteria are applied to the finished milk.

HISTORICAL

Development of HTST Pasteurization

The discoveries of Louis Pasteur that bacteria which cause "disease" of wine could be killed if heat is applied for a sufficient period of time, led to the scientific development of milk processing. This process is now universally called "Pasteurization". Weigmann's treatise on "Pasteurization and Sterilization of Milk" (1893) is one of the oldest known records of the step-by-step development of the process and machinery for pasteurization up to 1893. Weigmann wrote of holding systems of regenerative heaters and coolers and of thermal death points years before interest in them became active in other parts of the world. He states that in 1881

Fesca of Berlin, Germany, invented the first continually working apparatus for the heating of milk for the purpose of preserving same and in 1886 Thiel invented the gravity flash pasteurizer. These flash pasteurizers were definitely of the "high-temperature short-time" type and represented the first steps in commercial pasteurization.

Public health regulations prohibited the commercial use of flash pasteurization because the equipment and controls then available made it difficult or impossible to pasteurize milk satisfactorily. When the milk was heated to 160°F. not all pathogenic bacteria were destroyed. Higher temperatures, such as 170°F., reduced creaming but gave good results bacteriologically. Further, there were no quick-acting accurate temperature controls, the flow rate was not constant, there was no definite holding time and the mixing of raw and pasteurized milk was possible. Under such circumstances public health officials justly condemned flash pasteurization and consequently, it was superceded by the commonly known holder method which could be more accurately controlled in commercial operation.

However, with improvements in automatic control devices and the use of hot water as a heating medium, milk could be made to flow at a controlled rate in a very thin layer over or between heated surfaces so that its temperature could be rapidly adjusted and regulated. This method provided more

accurate control of time and temperature and thus has become known as the "high-temperature short-time" modification of the process of flash pasteurization. HTST pasteurization presented new problems but soon gained the confidence of public health officials and thus has become a legal method of pasteurization in many parts of the world.

For various reasons the holder method is now being rapidly replaced by the HTST method. Yale (1933), reviewed the development of HTST pasteurizers in which provision was made for the control of the holding time for very short periods of time at temperatures in the range of 160°F. The first American pasteurizer of this type was the Electropure, manufactured by the Trumbell Electric Mfg. Co., Plainville, Conn. This pasteurizer was a modification of an earlier electrical pasteurizer based on the developments in electrical pasteurization in England in the period 1913 to 1920. The first models were essentially flash pasteurizers as the holding time was estimated as being about 3 to 4 seconds; subsequent modifications studied in 1927 are reported to have had holding times between the heater outlet and the cooler inlet ranging from 11.1 to 19.7 seconds. Other types of HTST pasteurizers using hot water and steam as heating mediums, including the plate pasteurizer developed in England, were introduced between 1920 and 1930.

Standards for Pasteurization

A review of the early literature reveals that the times and temperatures recommended for heating milk showed wide variation and uncertainty. Variation in the reports of bacteriologists on the thermal death times of pathogenic bacteria was one of the chief reasons that no single standard for pasteurization was recognized. Another cause for uncertainty in any one standard was the variation in the temperatures and times recommended by leading bacteriologists of that time.

According to investigations reported by North et al (1925) temperature-time combinations of 140°F. for 15 to 30 minutes were sufficient to destroy Mycobacterium tuberculosis. Consequently, in 1911 and again in 1917 the National Commission on Milk Standards in New York recommended 145°F. for 30 minutes. However, this standard was soon shown to have an injurious effect on the creaming properties of the milk and as a result many areas adopted a standard of 142°F. for 30 minutes. The Endicott experiments of 1921-1923, conducted by North et al, confirmed the safety of the adopted standard of 142°F. for 30 minutes. However, they recommended that in order to conform to this standard the industry must adjust the temperature of pasteurizing machines to a degree or two above the minimum temperature of 142°F. to allow for fluctuations. This led to the present minimum standard of 143°F. for 30 minutes for low temperature pasteurization in the U.S.A. and Canada.

At this time there was no acceptable standard for HTST pasteurization as it was not considered a dependable process. However, due to improvements in design of heaters, and in temperature control and safety devices, there developed a demand for recognition of this process as a dependable method of pasteurization. As a result, the U.S. Public Health Service in cooperation with the New York State, New York City and Pennsylvania State Health Departments in 1927 initiated studies on HTST pasteurizers. Moss (1940) and Fuchs (1951) both report that on the basis of this work the standard of a minimum of 160°F. for a minimum holding time of 15 seconds was recommended. Holland and Dahlberg (1940) report that around 1927 the New York Standard for HTST pasteurization was set at a minimum of 160°F. for a minimum holding of 20 seconds, this standard being subsequently modified to 15 seconds holding at the same temperature. The U.S. Public Health Service Milk Ordinance and Code (1939) demands for HTST pasteurization heating to a minimum of 160°F. for a minimum holding time of 15 seconds. This, according to Fuchs (1951), was changed in 1949 to 161°F. for the same holding period, the change being based on the findings and recommendations of Sanders and Sager (1948) regarding phosphatase inactivation.

In Canada we do not have a standard ordinance and code for the handling of milk such as that prepared by the U.S. Public Health Service. However, the same temperature has been

adopted by some provinces but the holding time has generally been set at a minimum of 16 seconds.

The following list shows the provincial regulations as of June, 1951*:

Province	Regulations
Newfoundland	nil
Prince Edward Island	161°F. - 16 seconds
Nova Scotia	161°F. - 16 seconds
New Brunswick	nil - will adopt U.S.P.H.S. regulations when necessary
Quebec	161°F. - 16 seconds
Ontario	161°F. - 16 seconds
Manitoba	161°F. - 16 seconds
Saskatchewan	160°F. - 15 seconds
Alberta	161°F. - 16 seconds
British Columbia	161°F. - 16 seconds

According to Wilson (1942) the HTST pasteurization standard in Great Britain is a minimum of 162°F. for a minimum of 15 seconds. However, according to Lethem (1950), this has now been amended to 161°F. for the same time. In Europe higher temperatures are commonly used and little if any regard is paid to the consequent reduction in cream volume.

*Information supplied by the various Provincial Departments of Public Health.

Thermal Death Times of Mycobacterium tuberculosis

The thermal death times of M. tuberculosis in the temperature range of holder pasteurization have received a great deal of study. The accepted fact that this organism is more resistant to heat than other pathogens likely to be present in milk was confirmed by Rosenau (1908). Further studies by North and Park (1927), Park (1927, a) and Park (1927, b) have attempted to establish the precise temperature-time combinations necessary to destroy this organism in milk. As a result, it is today generally accepted that this bacterium is killed in milk at 142°F. in 10 minutes.

No equivalent data are available for the temperature range of HTST pasteurization but the studies of North and Park (1927) have carried much weight in establishing standards in this range. Since bacterial death is logarithmic, Dahlberg (1932) in plotting North and Park's data on semi-logarithmic paper obtained a straight line death curve. The resulting curve cuts the 160°F. line at 11.2 seconds. There is at present no experimental proof to confirm this extrapolated result. If the data of North and Park had represented true "thermal death points" then extrapolation may have been justified. Wilson (1942) in reviewing the investigations on this subject attempts to justify a thermal death time for this pathogen of 12 seconds at 160°F. Park (1927, b) indicated the thermal

death point of tubercle bacilli in milk at 160°F. as 30 seconds.

In recent years a new conception of bacterial destruction has developed. According to Ball (1943) the trend appears to be away from the procedures that show absolute destruction points and toward those that reveal rates of destruction of bacteria. In the broadest sense, therefore, theoretically there is no "thermal death time". Universal recognition is given to this conception in the canning industry and their processes are now based on death rates rather than thermal death points. These rate-of-destruction curves when plotted on semi-logarithmic co-ordinates yield straight line curves since bacterial destruction is logarithmic. Thus the Z value of these straight line destruction curves becomes an important factor in the evaluation of the thermal process.

The "thermal death time" curve in Dahlberg's analysis of the North and Park data has a Z value of 10.5°F. while Park's (1927, a) data analysed the same way have a Z value of 12.8°F. Thus, considerable variation is evident which is caused by the inconsistency of the results to form a perfect straight line destruction curve. Obviously, techniques would cause such a variation. On careful analysis of the North and Park data in a manner similar to Dahlberg's, one finds a distinct area in which the true "thermal death times" probably lie. Further, on extrapolation into the region of HTST pasteurization the "thermal death time" is found to be between 12 and

20 seconds at 160°F. Thus, the precise temperature-time relationships for M. tuberculosis are not definitely known but it seems, from the data mentioned, that the Z value lies in the neighborhood of 10.5-13°F.

The Z value of the M. tuberculosis thermal death curve has a very important bearing on present conceptions of pasteurization. The inactivation of milk phosphatase has become the universal routine test for proper pasteurization. Although there is still much to be learned about the inactivation and temperature-time relations, nevertheless, the test can be reasonably soundly applied in low temperature long time (usually abbreviated to LTLT) pasteurization. As in the case of M. tuberculosis, the relation to HTST pasteurization is still somewhat obscure. If the Z value for inactivation of phosphatase lies between 8 and 9°F. as reported by Lear and Foster (1949), then it appears that the two destruction curves must cross at some point in the region of HTST pasteurization.

That commercial HTST pasteurization is giving adequate protection is confirmed by the studies which have been made of commercial machines. Hiscox (1944) reviewed these in 1944. The results are from various parts of the world and although they do not represent true "thermal death times" evidence is presented that the times and temperatures at which the plants operated were sufficient to insure the destruction of all tubercle bacilli.

Development of Phosphatase Test

The need for a practical test for detecting the degree of heat-treatment of milk has been felt for some time. Bacterial counts, recording thermometer charts and plant inspection do not always furnish reliable means of ascertaining that milk has been properly pasteurized.

The heating of milk inactivates more or less completely the enzymes which were originally present in the raw milk. Consequently, several tests for pasteurization have been developed based on this inactivation. The completeness of the enzyme destruction obviously depends very largely on the temperature and the time during which the milk has been exposed to heat and on the specific characteristics of the individual enzyme. The enzyme peroxidase has been used as the basis of pasteurization tests but this enzyme is not inactivated until the heating is carried to about 170°F. which is not suitable today. The amylase test had considerable use but lacked sensitivity, while the catalase, protease and lipase tests for pasteurization have not been successful because of their heat inactivation characteristics.

Kay and Graham (1934) claimed that at any temperature from 140°-167°F. 96% destruction of phosphatase indicates complete destruction of M. tuberculosis. Shortly after this Kay and Graham (1935) reported the phosphatase test for pasteurized milk. The development of this test has provided a tool for

the control of pasteurization which has not yet reached the limit of its potential usefulness. The test was developed for British standards of pasteurization, i.e., 145°-150°F. for 30 minutes, and according to Fasken and McClure (1940) slight modifications are needed to make the original test suitable for examination of milk pasteurized at 143°F. for 30 minutes. Modifications and improvements of the original test, up to 1939, are reviewed by Burgwald (1939).

In 1948, after extensive study, the phosphatase test, as modified by Sanders and Sager (1947), was made an official method by the Association of Official Agricultural Chemists (1948) for testing fluid milk, cream, cheddar-type cheeses and the soft unripened cheeses as an index of the adequacy of pasteurization. The test of Sanders and Sager was adopted because it was more sensitive than preceding tests. A raw milk contamination of 0.1% in pasteurized milk is detectable visually and a concentration of 0.05% can be detected with a photo-electric colorimeter.

The Nature of Phosphatase

The enzyme phosphatase is a specific esterase which will hydrolyse esters of phosphoric acid. Since its first discovery in 1907 it has become increasingly important and it has now been established that some 15-20 phosphatases exist. Because of their importance in bone formation, carbohydrate metabolism

etc., we find them present in practically all living cells and in many biological fluids. The phosphatases are generally divided into two groups: alkaline phosphatase, with an optimum pH of from 8 to 10, and acid phosphatase with an optimum pH of from 4 to 5.

Milk normally contains both the alkaline and acid phosphatases. According to Mullen (1950) the concentration of the acid phosphatase in milk is low, being about one fortieth of the concentration of the alkaline phosphatase. Very little is definitely known about the chemical constitution of the phosphatases in milk. Since all enzymes are now thought of as being protein or protein-related materials it is reasonable to assume that phosphatase is at least partly protein in nature. These views are borne out by Massart and Vandendriessche (1945) who suggest that milk phosphatase is a "heavy metal (zinc) proteid". Andersen (1949) explains certain observations on alkaline phosphatases, by assuming that the protein of the enzyme is a mixture of several components which may be, according to Moelwyn-Hughes (1940), at different stages in their electrolytic dissociation. Qualitatively, however, the nature of the enzyme protein or associated protein may be related to the degree of specificity of the enzyme action. As to the protein nature itself, those enzymes thus far reported in the literature as crystalline and substantially pure are protein in nature. In this form, however, they may require for effective action coenzymes or other materials which are themselves inactive.

As yet, no practical use has been made of the acid phosphatase which is present in normal raw milk. According to Mullen (1950) this enzyme possesses properties of thermostability being only 10-20% inactivated by the normal conditions of pasteurization. The enzyme, however, exhibits considerable instability towards visible radiation, being 50% inactivated by 60 minute exposure to spring sunlight, and is inhibited by chloroform and formaldehyde. In contrast, the alkaline phosphatase which is present in normal raw milk has a practical value. It is inactivated during pasteurization and this property has been made use of in the development of the phosphatase test for pasteurization. It is also very stable, being unaffected by several preservatives. Alkaline phosphatase has received considerably more attention than the acid enzyme in milk and therefore any further reference to phosphatase in this report shall mean the alkaline phosphatase unless otherwise stated.

The location of phosphatase in normal milk has been investigated by several authors. Invariably they report that it is located to a large extent, but not entirely, at the fat-serum interface. Kay and Graham (1934) believe it to be present either in the very thin, mainly protein, layer which covers the fat globules or is adsorbed on the fat globules in such a way that the greater part of it may be removed by further

treatment, e.g. churning. Further they report that on centrifuging melted butter nearly all the enzyme present is found dissolved in the aqueous portion which shows that the enzyme is probably not even in part fat-soluble. Sjostrom (1949) proposes a similar theory suggesting that milk phosphatase is linked with the proteins rather than with the lipoids of the fat-globule membrane. Hetrick and Tracy (1948) show that the enzyme probably is concentrated at the fat-serum interface, perhaps in a manner similar to agglutinin, since butter oil had no phosphatase activity and the buttermilk exhibited an activity approximately ten times that of skim milk. According to Rimpila and Palmer (1935) most of the phosphatase in cream appears to be so tenaciously adsorbed to the fat globule that even washing six times with distilled water failed to remove more than 50% from the cream. These observations led them to conclude definitely that the enzyme in cream is a constituent of the fat globule "membrane" and cannot be washed away with water.

The presence of phosphatase, like that of so many other enzymes, is indicated by activity rather than isolation. In the phosphatase test for pasteurization the presence of the enzyme is indicated by the liberation of phenol from di-sodium phenylphosphate by the activity of the enzyme. The phenol is then allowed to react with B.Q.C. (2,6-dibromoquinonechloroimide) and the resulting blue color lends itself to colorimetric analysis.

Inactivation of Phosphatase

Bigelow (1921) observed the logarithmic nature of the thermal death times of bacterial spores at different process temperatures. These data, when plotted on semi-logarithmic paper, usually describe a straight line. The literature on the study of heat inactivation of milk phosphatase in the region of HTST pasteurization indicates that the rate of inactivation is rapid and, according to Kay and Graham (1935), Koppejan (1936) and Van Bever and Straub (1943), follows a mono-molecular law, i.e., is a first order reaction. However, other results seem to indicate that the inactivation is not strictly first order but, as Hetrick and Tracy (1948) mention, possibly a pseudo-first order reaction. According to Andersen (1949) the great increase in the velocity of destruction, caused by the rise in temperature, follows the Arrhenius equation. This means that the temperature-time relationships form a straight line when plotted in a semi-logarithmic manner. However, several investigators have shown that a plot of temperature vs. the log time for inactivation at that temperature yields a straight line. This observation becomes important in the evaluation of the thermal process.

Marquardt and Dahlberg's (1931) analysis of creaming results by the use of semi-logarithmic paper drew attention to this method for the analysis of creaming data which exhibit logarithmic phenomena. Kay and Graham (1934) established the

temperature-time combination necessary to destroy 96% of the phosphatase in milk and plotting these in a logarithmic form they obtained a straight line curve. On the same graph they plotted the straight line curve developed from the North and Park (1927) data by Dahlberg (1932). On analysing these two curves they attempted to justify the adequacy of the phosphatase test over the range 140°-167°F. The Z value of their destruction curve is approximately 11.7°F. which is quite different from that obtained by other authors. This is probably due to inaccuracies in measurements at higher temperatures since their shortest holding time was only 20 seconds.

Since Kay and Graham's original analysis of the inactivation of phosphatase, several authors have again attempted to establish the temperature-time relationships necessary for the destruction. Holland and Dahlberg (1940) devised an experimental apparatus whereby the heating-up period was only from 3 to 10 seconds depending on the desired temperature. This method reduced the heating-up period considerably but no mention is made of the cooling time. Presumably, the samples were removed and placed in an ice bath. When their results were plotted on semi-logarithmic paper a straight line curve over the range 140°-165°F. was obtained, the Z value of this being 8.35°F. The fact that the lower portion of the curve is not a straight line probably indicates that control of conditions at high temperatures are more important than similar controls at lower temperatures.

Sanders and Sager (1948), again using a laboratory pasteurizer, established a temperature-time combination which when plotted on appropriate paper gave a Z value of 8.73°F. In this apparatus the milk required 6 seconds to be heated to the desired holding temperature, where it was held for periods of time which were accurate to ±3 seconds, while removed samples were cooled in ice water. However, they attempt to justify heating-time lags by subtracting either 3 or 4 seconds, depending on sample size, from their total heated times.

Hetrick and Tracy (1948) reported a straight line curve, for inactivation of phosphatase, which has a Z value of 9°F. They used a Mallory small-tube heat exchanger as their heat treating apparatus and reported that with this unit only 0.83 seconds were necessary to heat the milk to the desired temperature. Samples were removed into test tubes which previously had been immersed in ice water but no times for cooling are reported.

Lear and Foster (1949) developed an apparatus for heat treating milk which required 7 ±1 seconds to reach the desired temperature. It was then held in a holding tube for a period of time which was accurate to ±3 seconds. Samples were removed by pipettes, after various time intervals, and cooled in ice water. With this unit the inactivation of phosphatase was studied and the reported straight line curve has a Z value of 8.82°F. Other Z values are reported by them and the significance of equal Z values is explained.

On examining the above mentioned straight line curves the following times are required to inactivate phosphatase at 160°F.:-

Authors	Time
Hetrick and Tracy (1948)	35.9 seconds
Sanders and Sager (1948)	24.0 "
Holland and Dahlberg (1940)	20.4 "
Lear and Foster (1949)	16.8 "

The results indicate considerable variation as to the required time necessary to produce the desired inactivation. There are probably three causes for this variation. Firstly, the methods of heat-treatment varied i.e., the heating-up and cooling periods were significantly different. Secondly, the methods of analysis for phosphatase varied. Thirdly, the end point chosen to indicate inactivation varied from as low as 0.5 ppm (Lear and Foster) to 40 ppm (Holland and Dahlberg).

The Sanders and Sager (1947) test for phosphatase inactivation has now been made the official method for analysis by the Association of Official Agricultural Chemists and with this test the criterion of pasteurization is 2 mmg. phenol/ 0.5 ml of milk which is equal to 4 ppm.

Creaming Inactivation

Extensive studies by Dahlberg and his associates (1929) (1931) (1932) (1940) claimed that the time-temperature combinations that result in a significant reduction in the creaming of milk are considerably above those required to destroy M. tuberculosis as shown by the data of North and Park. When they plotted these data and a line joining the standards of pasteurization on semi-logarithmic paper a considerable margin is to be observed between the pasteurization standards and significant reduction in creaming. This margin of safety as regards creaming is greatest for low temperature pasteurization and least in the region of HTST pasteurization where it is approximately 9 seconds.

Early standards for milk pasteurization on this continent included a maximum as well as a minimum temperature but experience with these standards soon demonstrated that the maximum temperature was determined by its effect on the cream layer. Consequently, present standards take cognizance of this fact. The principle that has been allowed is to set the minimum temperature as close to the point of cream volume interference as is practical taking into consideration the sensitivity of controller and recording thermometer. The change in the standard for holder pasteurization from the former 142°F. to the present minimum of 143°F. was made on this basis.

The literature on the creaming of milk is extensive and no attempt will be made to review it. This subject is thoroughly covered by Dahlberg and Marquardt (1929) and more recently by Dunkley and Sommer (1944). The main interest will be with information on methods of measuring and interpreting significant impairment of creaming.

Holland and Dahlberg (1940) outline the method that was employed in their studies and by others in the measurement and comparison of cream volumes. In this method the milk being studied is placed in 100 ml measuring cylinders that are stored in an ice-water bath. Storage is not necessarily maintained at this temperature and is usually at around 40°F. for a period of 24 hours. In order to measure the effect of various time-temperature treatments on cream volume a control is used that has been heated momentarily to 140°F. followed by rapid cooling to 40°F. The temperature to which the control is heated only needs to be sufficiently high to liquefy the fat which according to Sharp and Krukovsky (1939) and Dunkley and Sommer (1944) will result in the desorption of euglobulin and be followed by its reorientation at the fat globule surfaces when solidification of the fat globules takes place. Heating to a temperature of 135°-140°F. momentarily insures thorough liquefaction of the fat globules and does not interfere with creaming. It is a procedure that was established prior to present knowledge of creaming.

There does not appear to be any standard procedure for interpreting significant reduction in cream volume when studying the effect of a range of time-temperature treatment of milk. Holland et al (1940) in experiments at HTST temperatures considered that a reduction of one ml in cream volume below the control was sufficient to indicate a definite destruction of creaming ability and the next shorter holding period was plotted as the longest holding time milk could be held at that temperature without influencing adversely the creaming properties of the milk. Marquardt and Dahlberg (1931) took the time-temperature treatment that gave the first reduction of 0.2 percent or more in the creaming index as the point of significant impairment of creaming. Dahlberg et al (1941) chose the commercial pasteurization of milk at 144°F. for 30 minutes as the endpoint and considered any reduction in cream volume below this point as significant. Millenky and Brueckner (1941) in a comparative study of HTST and LTLT pasteurization conclude that a 2 percent difference in the cream volume is not noticeable when milk bottles containing milk with varying cream volume percentages were examined. It will be obvious that the significance of a 2 percent difference in the cream volume of bottled milk will depend upon the butterfat content of the milk and the shape of the upper portion of the bottle.

Pumping Characteristics of Milk and Water

The rotary pumps extensively used on HTST pasteurizers have positive displacement, which means that the fluid is delivered to the discharge pipe in successive isolated quantities under positive pressure. These isolated quantities may be small or large depending on the particular characteristics of the pump. Because such pumps have close mechanical clearances, there is little loss due to slip when the liquid being pumped is of high viscosity. The volumetric efficiency is, however, affected by variations in:-

1. Pump speed.
2. Pressure at discharge.
3. Viscosity of the material being pumped.
4. Vacuum on suction side.
5. Amount of entrained air or gas in material being pumped.

The pump may be operated at a speed above that at which its passages will be completely filled and, therefore, the volumetric efficiency will be decreased.

According to accepted theories of hydraulics, as the pressure at the discharge increases, the material being pumped tends to be forced back through the clearances to the suction side of the pump. This material, the slip, increases not only with the discharge pressure but also with a decrease in

the viscosity of the materials being pumped. Theoretical displacement minus actual displacement equals slip, and as slip increases, the volumetric efficiency decreases.

With an increase of vacuum at the suction side of the pump, because of high suction lift or a long or crooked suction pipe, the entrained air or gas in the material being pumped will naturally expand and will occupy more of the pump displacement. A smaller portion of the displacement, therefore, will be left for the liquid and the volumetric efficiency will decrease.

The effect of viscosity on volumetric efficiency is related to pump speed as well as discharge pressure. At pump speeds that are low enough to permit the pump to fill, volumetric efficiency increases with viscosity because a more viscous liquid forms a better seal.

Milk and water differ in their physical properties. According to Sommer (1946) the viscosity of milk at 30°C. is 1.640 cp. while that of water is only 0.801 cp. Their specific gravities also vary, milk being slightly higher, at 1.032. It is conceivable that these differences might be reflected in their pumping characteristics. Weber (1947) reports increases of milk flow over water flow in a study of commercial pasteurizers of from 0 to 25 percent, with the same pump setting. No explanation is offered in those cases where no

increase took place. Cuttell (1948) reports that the milk-rate will be slightly higher than the water rate under the same plant conditions. He attributes this increased milk flow rate over water to the greater density and viscosity of milk. However, no experimental evidence is given. Robinson and Moss (1948) studied 34 commercial HTST pasteurizers and found that because of the increased capacity on milk over that on water the holding time may be decreased as much as 26.7 percent.

Measuring Holding Time

The requirement of a minimum of 15 to 16 seconds holding time in HTST pasteurization introduced the problem of developing methods for measuring accurately the time of milk flow through the holder of HTST pasteurizers. The following are the methods that have been developed for this purpose:-

1. Dye or visual.
2. Salt or conductivity.
3. Thermal.
4. Bacterial.

Both the dye and salt methods are adaptations from hydraulic engineering. The dye method was used extensively in the timing of retarder and other continuous flow pasteurizers. Its use in timing HTST holders has been discontinued on this

continent mainly because it cannot be used when pasteurizing milk and endpoint recognition is difficult. Cuttell (1948) states that this method is still extensively used in Great Britain. According to Dummett and Mongar (1948) the sensitivity of the dye method corresponds to a dilution of about 1 to 5,000, while a modification of this method which they developed using nickel chloride with dimethylglyoxime as a detector has a sensitivity of 1 in 100,000.

The salt or conductivity method is being used and tested extensively at the present time on this continent. The method as applied to the HTST pasteurizer is described by Roger (1939) and Fay and Fraser (1943). According to Weber (1947) it is quite complicated and cannot be used directly on milk, it is not standardized and its accuracy is unknown. In a recent investigation Jordan (1949) studied this method extensively and determined that dye, salt, and bacteria are all transported at the same rate by a stream of flowing water. He concludes that, if sensitive means are used to measure dye and salt, these substances can be employed to measure the holding time of bacteria under the same conditions. Robinson and Moss (1948) found that a range in volume of injection of saturated NaCl solution from 50 to 150 ml had little effect on the holding time measurements when tests were made on large installations.

Thomasson (1945) introduced a thermal method of timing based on temperature changes recorded by the recording thermometer when cold pasteurized milk was introduced at the entrance

of the holding tube. Robinson and Moss (1948) used a modification of this method on a number of commercial pasteurizers and compared it with the salt method. They reported the thermal method, in which the fluctuation of the recording thermometer needle was taken as the end point, to give holding times 1.81 seconds longer on the average than the salt method. This increased time is undoubtedly caused by a number of factors such as the sensitivity and response of the recorder-controller. Jordan (1949) reports some preliminary results in a comparison of an improved thermal timer manufactured by the Foxboro Company, Foxboro, Massachusetts, based on the measurement of a thermal wave produced in the heater section of the pasteurizer, thus eliminating criticism of the injection of solutions into the holding tube. The preliminary results indicate that this method, comparable in accuracy to the salt test, can be used on milk while the pasteurizer is in operation.

It should also be noted that the injection of bacteria into the holding tube has been employed as another method of measuring flow time.

All the test methods reported in the literature for checking the holding time of HTST pasteurizers are based on the measurement of the holding time in the holder, a tubular section extending from the outlet of the heater section to the location of the sensitive bulbs of the indicating thermometer

and the controller-recorder. The length of time required for the fastest particle of milk to pass through this section of the pasteurizer represents only a part of the time that the milk is subjected to temperatures that are lethal to bacteria. In fact in some installations it may represent only approximately 50 percent of the time that the milk is at or above 160°F. In this connection it is interesting to note that unpublished data of the New York State Department of Health, made in the early days of HTST pasteurization and reported by Weber (1947), show the inactivation of large inoculations of M. tuberculosis at 158°F. for a calculated holding time of 2.2 to 3.7 seconds in the Electropure pasteurizer; and 152°F. when samples were taken at the outlet of the heater of a plate-type pasteurizer. These results point to the importance of the unmeasured or unknown time that is not measured in testing the holding tube but is of importance in the pasteurization of the milk. In addition to the lethal effect of the time-temperature factor in heating the milk to 160°F. or above there is the influence of the untimed portion of the milk above 160°F. and the time that the milk is subjected to a lethal time-temperature factor during cooling. It appears that if the holding time is to be controlled then the whole time that the milk is subjected to a temperature lethal to bacteria should be measured. It is doubtful whether this procedure is routinely feasible in commercial practice but an interesting application of this

principle was studied by Dahlberg et al (1941) in what they termed "Quick-Time" pasteurization. In this modification of pasteurization, the milk was heated for intervals of 5, 6, 12, and 24 seconds above 140°F. with maximum temperatures in the range of 169°-177.5°F. They report that at the higher temperatures there appears to be a greater margin between the temperature at which creaming is impaired and the temperature that gave milk with a negative phosphatase test than existed in pasteurization at lower temperatures.

EXPERIMENTAL

I. Methods

(a) Type of Pasteurizer

The plate-type HTST pasteurizer used in this study is shown in Figure 1. This pasteurizer was arranged for a capacity of 1000 pounds of milk per hour. It was equipped with a Waukesha positive displacement pump, a type of pump used exclusively in the United States and Canada. The pump was located between the regenerative and heating sections of the pasteurizer in order to assure a higher pressure on the pasteurized milk in this section of the pasteurizer, which is a requirement of the U. S. Public Health Service (1939). This requirement is for the purpose of insuring

that the raw milk will always be under negative pressure and thus any leaks that might develop in the exchanger, because of flaws in the metal parts, will not permit entry of raw milk into the pasteurized product. In England protection in this regard is not insisted on and controlled centrifugal pumps are used.

The float control tank was located below the milk level in the pasteurizer, another provision to assure negative pressure on the unpasteurized milk in the regenerator. The milk was maintained at a uniform level in the float control tank and it was kept well stirred in order to assure a uniform fat content.

The study was conducted during the summers of 1949, 1950 and 1951. Recommendations at the end of the first and second summers resulted in alterations to the pasteurizer and thus completely comparable conditions did not exist throughout the investigation. However, most of the data used are from the observations of the last two mentioned years during which time the plate arrangements differed. Thus the 1950 and 1951 conditions are referred to as plate arrangement A and B respectively. Results are recorded according to the particular plate arrangement of the pasteurizer and thus are indicative of the particular conditions for that year.

To provide various thermal treatments, in the range of HTST pasteurization, the pasteurizer was modified by varying the holding tubes, which were carefully sloped upwards to prevent entrapment of air.

(b) Source of Milk

The milk, ranging from 2.7 to 4.0% fat content, was supplied from the milk storage tank of one of the local dairies. The milk at the lower end of this range was rather low in milk fat for mixed milk from a number of herds but is accounted for in part at least by the predominance of Holstein cattle in the Edmonton milk shed. There may have been occasions when the milk in the storage tank was largely from one herd as the selection and shipment of the milk was not supervised beyond the request that it be taken from the storage tank in order to give better assurance of average milk.

(c) Sampling Procedure

The pasteurizer was operated on water until the operating conditions were stabilized and the timing and flow rate measurements completed. The water was then displaced with milk and the heat-treatment of the milk proceeded with. The temperature of the heat-treatment was lowered to the lowest temperature necessary for that particular series and then gradually raised to the maximum temperature desired. Samples for phosphatase and creaming tests were taken off the cooler section at 40°-45°F. The time for the milk to flow from the indicating thermometer location, at the end of the holding tube, to the outlet of the cooler was determined and this time interval was employed to set the time of sampling at each temperature interval studied.

(d) Timing Measurements

All flow-time measurements reported in this study were made with the salt test when operating the pasteurizer on tap water, employing essentially the method as outlined by Fay and Fraser (1943). The measurements were made just prior to heat-treatment of milk in each trial. At first the electrodes were mounted in rubber stoppers that were fitted into openings at the upstream end of the holding tube, the downstream end of the holding tube, the pasteurized milk entrance to the regenerator and the cold pasteurized milk outlet of the pasteurizer. Fourteen gauge copper wire electrodes were 2 mm. apart and 2 cm. long as recommended by Jordan et al (1949). Later electrodes recommended for the 3A* Standard Method for Determining the Holding Time of HTST Pasteurizers by Means of the Salt Conductivity Test (1950), were used wherever possible. No differences were observed in the timing measurements when these electrodes were compared. The saturated salt solution was injected manually in 40 ml quantities, through a spray type nozzle to avoid impelling the solution in the direction of flow. All time intervals were measured manually with a stop-watch.

*Formulated by the International Association of Milk and Food Sanitarians, the United States Public Health Service and the Dairy Industry Committee.

Electrodes of 32 gauge sheet tin, insulated with Minnesota Mining and Manufacturing Company special electrical tape No. 33, were inserted between the plates for measuring flow-times between selected points. These electrodes were found to be as sensitive as the regular electrodes previously described. Some difficulty was experienced in preventing short circuits because the space between the plates was only 1-2 mm.

(e) Definition of Terms

Rate of flow:- the pounds of milk or water delivered within a given time measured with a stop watch, the time being usually 5 minutes and from this the rate, in pounds or gallons per hour, is calculated.

Holding time:- the flow-time measured from the outlet of the heater to the location of the indicating thermometer and controller-bulb at the end of the holding tube. The holding times reported refer to calculated milk holding times unless otherwise stated.

Pipeline time:- the flow-time measured from the outlet of the heater to the pasteurized milk inlet to the regenerator.

Control time:- is the measured time during which the medium is not below the controlled temperature.

Milk flow-times:- are calculated times found by multiplying water flow-time by the ratio water flow-rate to milk flow-rate at the same pump setting.

Creaming index:- the numerical figure obtained by dividing the cream volume in percentage by the milk fat content of the milk in percentage.

(f) Phosphatase Inactivation

Because of its accuracy the phosphatase test as developed by Sanders and Sager (1947) was used in all determinations of phosphatase, with no important deviation from their method as laid down by the Association of Official Agricultural Chemists (1948). Color transmission was measured at 600 mu, using an Evelyn photo-electric colorimeter with 10 ml tubes. The quantities of phenol, after consideration of the controls, were read directly from a standard transmission-concentration curve prepared with known amounts of phenol. All samples were tested the day following the heat-treatments and were stored in the interval between sampling and testing at a temperature of 40°F. A negative phosphatase test indicating pasteurization of milk is signified by a phenol level of 2 mmg per 0.5 ml of milk which is equal to 4 p.p.m. of phenol. In this investigation the procedure adopted by Sanders and Sager (1948) of reporting phosphatase activity as units of phosphatase rather than the concentration of phenol in p.p.m. was followed.

(g) Creaming Measurements

Cream volume measurements were all made in duplicate on 100 ml of milk in 100 ml graduated cylinders. The milk as taken from the cooler outlet of the pasteurizer was poured into the measuring cylinders, leveled at the 100 ml mark, and placed in ice water. At the end of 4 hours and 24 hours the cream volume was measured with calipers and recorded in percentage. After the 4-hour reading the cylinders were maintained at 40°F. until the 24-hour reading.

The cylinders were carefully selected and only those with an accuracy within ±0.5 ml were used.

The control or activated sample was heated to 140°F. momentarily and then cooled quickly to 45°F. through a copper coil suspended in ice water.

The 24-hour creaming measurements only are reported as it has been shown by Millenky and Brueckner (1941) that the cream volume of milk pasteurized in HTST pasteurizers reaches a maximum in 24 hours.

In the present study, on significant cream volume destruction, the cream volume in percentage is reported. This procedure was also adopted by Holland and Dahlberg (1940). For graphic presentation it was considered that a reduction of 1 ml in cream volume was sufficient to indicate definite destruction of creaming ability. This represents a change of 1% in the cream volume since 100 ml graduates were used.

(h) Temperature Measurements

All thermocouples and indicating thermometers were calibrated against a thermometer graduated to 0.1°C. and certified by the Physics Division of the National Research Council to 0.01°C. All temperatures reported herein are corrected to the nearest 0.1°F. on this basis.

Temperatures between the plates were calculated from readings of thermocouples of Leeds and Northrup copper and constantan wires held between the plates at a constant distance of 2 inches from the peripheral rubber gaskets. Insulation for the wires was provided where required and care was exercised to minimize interference with liquid flow.

II. Results

(a) Performance of the Experimental HTST Pasteurizer

(1) Holding Tube Difficulties

The first holding tube provided with the pasteurizer consisted of a vertical U-tube extending downward from the outlet of the heater section at the top of the pasteurizer to the flow diversion valve. Calculated holding times for milk in this holding tube, based upon water flow measurements, were in the neighborhood of 7 seconds when the pasteurizer was operating at approximately its rated capacity. Thus the pasteurizer did not meet the specified holding time requirements.

Further investigation showed that considerable air was entrapped in this U-tube, which was, therefore, modified to give a gradual rise or slope to the line thus preventing any entrapment of air in this section of the machine. Calculated milk holding times could then be varied within the range 15-16 seconds.

(2) Air Pockets

The plate heat-exchanger and pipeline accessories other than the holding tube also offer many possibilities for entrapping air. It seems probable that air locks may influence the non-holding pasteurizing time in a manner similar to their effect in the holding tube. This aspect of the problem of HTST pasteurization was investigated further by making temperature measurements with thermocouples at the edges of the plates. Whenever the liquid entered the plate section at the top, it appeared that air would rise and block off a section of the plate to the downward flowing liquid. Thus, a portion of the plate would be considerably higher in temperature because of the lack of circulation. This was shown by observing temperature differences across the plates of as high as 38°F. When the liquid entered the plate section at the bottom then no air pocket would accumulate because the rising liquid would force the air out of the section. Evidence of this was indicated by temperature measurements being the same at selected points across the plates.

Figure 2 illustrates the deposit of milk stone, etc., that accumulated on the first two plates, first pass, in the heater section. This accumulation was allowed to gather over a considerable period of time using plate arrangement B. An examination of the plates clearly establishes two areas; the area of deposit and the relatively clean area probably produced by the turbulence of the flowing liquid. Thus a relatively quiescent pocket is established in this particular section of the pasteurizer. It is believed that, when the pasteurizer is operated on milk, this area is occupied by a foam and, thus, the excessive heat would cause the "baking on" of milk solids, resulting in the diagram displayed on the photographed plates.

(3) Leak Through Flow Diversion Valve

The Taylor Flow Diversion valve, model 39VJI, with which this pasteurizer is equipped, has a milk-tight but ungasketed diversion port. During the course of the trials water leakage past this port was observed to be as high as 2.5% of the total flow. This leakage was collected and added to the regular flow in all water flow-rate measurements. No leakage was observed when milk was being pasteurized.

(4) Time Required to Stabilize

When the pasteurizer was operated on water it was observed that there was a gradual decrease in the capacity until a point of stability was reached. This is shown by the following typical results of changing flow rates observed

during five different trials:-

Time - Min.	Flow rates in pounds per hour				
5	810	942	906	834	960
11	804	930	876	824	942
18	798	930	876	822	924
24	792	930	876	816	924
31	792	924	876	816	918
43	792	924	-	816	936

Therefore, the pasteurizer was operated for a period of time not less than 30 minutes, before any timing measurements were made. No attempt was made to determine the cause of this diminishing rate of flow.

(5) Pumping Difficulties

The Waukesha positive displacement pump provided with the HTST pasteurizer presented many difficulties in pumping. However, after several rearrangements of the plates, many of the earlier observed difficulties were overcome. Since air leaks on the suction side had a marked effect on pumping efficiency it became necessary to prime the pump whenever a trial was started. Once the seals of the pump became wet priming was not always necessary. Pressure measurements made during operation indicated the pump was operating under a head pressure of from 5-6 lbs. while the suction pressure was so small that measurements were not possible with the gauges used.

(6) Holding Time on Diverted Flow

Some HTST pasteurizers are equipped with a restrictor fitting in the diversion line. The purpose of this restrictor fitting is to maintain an equal head pressure during the operation of the pasteurizer in either forward or diverted flow thereby preventing reduction in the holding time. The machine under study was not equipped with a restrictor fitting and thus holding times for forward and diverted flows differed. The following results, made during a normal operation, indicate that the water holding time on diverted flow is approximately 2 seconds less than the normal holding time in the pasteurizer under observation.

Direction of Flow	Holding Times in Seconds		
Forward	18.2	18.2	18.2
Diverted	16.0	15.6	15.8

(b) Water and Milk Flow Rates

During the course of the study comparative flow rates with water and milk were recorded on all trials. The milk flow-rate, for each trial, was made at the same pump setting as that for the water. The rates of flow were obtained in pounds per hour and then converted to gallons per hour. This procedure eliminates any difference in capacity due to the greater density of milk. Since approximately 75 trials were

completed, no attempt is made here to report all the data. However, in no trial was the milk flow less than the water flow. The lowest increase in milk flow was 3.7% while the highest was 21.1%. This would seem to compare favorably with the results of Weber (1947) who reports increases of milk over water of from 0 to 25%.

The fact that the speed of the pump influences the milk-water ratio is indicated by Table 1. These data are from the trials with plate arrangement A and indicate that at high pump speeds the percent increase is low, e.g., 5.1%, while at very low speeds the percent increase is high, e.g., 17.1%. The reason for such variability has already been explained on the differences in viscosity of the two liquids.

The percent increase in milk flow is not constant when the pump is set at any particular capacity on water. The data reported in Table 2 were made with plate arrangement B and an attempt was made to operate the pump at the same water capacity throughout. Increases ranged from as low as 10.4% to as high as 21.1%. Since the pump speed was not altered and since the same relative viscosity difference would remain fairly constant, it is evident that other factors must also affect the ratio. Weber attributes such variations to several factors. Firstly, variations in line voltage will affect pump speed and thus vary the ratio. Secondly the pressure on the plates will affect the load on the pump. However, in

these trials the plate pressure was not varied once the pump was operating at the desired water capacity. Thirdly, air leaks on the suction side of the pump will cause changes in capacity. It is believed that these air leaks, particularly at the gasketed edges of the plates, were the major factor in varying the milk and water flow ratio. This factor may be magnified in pasteurizers of small capacity because gasket length per unit volume of liquid is greater.

(c) Internal Temperature and Time Measurements

In the interpretation of pasteurization efficiency of commercial HTST plants it is important to bear in mind that the milk is held at a lethal temperature for an appreciably longer period than is indicated by the holding time. Thus a margin of safety is provided which is of variable magnitude depending upon the particular characteristics of the pasteurizing unit. In order to determine times at lethal temperatures in the unit under study, thermocouples were carefully inserted between the plates and observed EMF readings were converted to ^{o}F. However, the plate arrangement for the machine was altered during the course of the observations, to obviate pumping difficulties. Therefore, measurements are presented here for both plate arrangements A and B. Figure 3 shows plate arrangement A while Figure 4 shows

plate arrangement B. The overall changes resulted in a smaller regenerative section and larger heater section in the B arrangement.

Thermocouple measurements were made on both milk and water and no internal temperature differences were measurable, i.e., the point where the medium reached 160°F. was essentially the same for water as for milk. However, timing measurements had to be made on water and the water-milk ratio was used to calculate the corresponding data for milk.

The two points of particular interest were 140°F. and 160°F. When these were determined, timing measurements at various locations throughout the pasteurizer were obtained and are summarized in Table 3.

The calculated milk times contained in Table 3 were used for constructing the flow diagrams illustrated in Figures 5 and 6. The slight differences are caused by the rearrangement of the plates. It should be noted that straight-line heating and cooling takes place in the regenerative section but the heating of the milk in the heating section is logarithmic. However, the important observation from these figures is that the so-called holding time of the pasteurizer studied represents only about 50% of the control time or actual time at the high temperature. It may be seen that the milk in this particular unit is held at 160°F. for 26-27 seconds which is in close agreement with results reported by

Rowlands (1950). Thus there seems to be a considerable factor of safety over and above the timing requirement of 15 seconds holding.

The conditions of heat-treatment with plate arrangement B are indicated in Table 4, the only variable being the pipeline time which was purposely varied in order to get several different heat-treatments. Therefore, the exact conditions of heat-treatment are known for each thermal effect studied. However, the lethality of the process, as indicated by phosphatase destruction, will also be affected by the short heating-up and cooling periods. An analysis of these two, thus, becomes necessary and is included in a later section.

(d) Inactivation of Phosphatase

(1) Rate of Destruction of Phosphatase

If the rate of destruction of phosphatase in milk is a first order reaction as indicated by Van Bever and Straub (1943) then a plot of the logarithms of the concentration against times at any particular temperature should yield a straight line. To determine the characteristics of this destruction, various lots of milk were heat-treated in the pasteurizer under varying conditions of time. Samples taken at various temperatures were analysed for phosphatase activity.

However, only the results for two temperatures are reported here since other temperatures bear less relationship to the temperature of HTST pasteurization. Results for 158.5°F. and 160.1°F. are reported in Table 5 and are plotted in a semi-logarithmic manner in Figure 7. The inconsistency of the results to form a perfect curve may, in part, be accounted for by the fact that each observation for any one temperature was made on a different lot of milk. However, from the results shown in Figure 7, it appears that as the destruction of phosphatase proceeded, the rate of destruction at constant temperature is very rapid at first and diminishes to a relatively very slow rate. This conforms to observations by Sanders and Sager (1948) and Hetrick and Tracy (1948) who report a similar deviation from a semi-logarithmic relationship.

Further observations on the characteristics of phosphatase destruction were determined by heat-treating milk in the pasteurizer under varying conditions of temperature but relatively constant time. The first observations were made with plate arrangement A and the results of phosphatase destruction are reported in Table 6. When the apparatus was altered to plate arrangement B the experiments on destruction of phosphatase were repeated and are reported in Table 7.

In Figures 8 and 9, the temperatures and average phosphatase values of Tables 6 and 7 are shown plotted on the

arithmetic and logarithmic scales respectively. The curves in both figures deviate from a straight-line course in a direction that indicates a marked decrease in the rate of inactivation as the temperature is increased, i.e., the rate of destruction of the enzyme by heat is most rapid at first but diminishes greatly as the concentration of active enzyme is reduced.

The curves in Figures 8 and 9 both show the deviation at a temperature of approximately 158.5°F. At temperatures below this there is considerable similarity between them. At the temperature of 158.5°F. the concentration of residual phosphatase is 0.8 units/0.5 ml milk in Figure 8 and 0.9 units/0.5 ml milk in Figure 9. Assuming an original raw milk concentration of 1000 units/0.5 ml milk, which is approximately the concentration according to Sanders and Sager (1948), these degrees of destruction would represent 99.92% and 99.91% respectively. This represents a destruction considerably greater than the 99.6% used by Andersen (1949) or Kay and Graham (1935), who thus would not encounter the deviation from the straight line course of destruction.

When 2 units of phosphatase/0.5 ml milk are considered the end-point, then inactivation is attained at 157.7°F. for both plate arrangements. This point is examined further in another section of this report. However, from this observation it appears that the pasteurizer, when operating at 161°F. and 15 seconds holding time, must provide a thermal treatment considerably above that necessary to inactivate phosphatase to the degree called for by the Official Test. Thus the

holding time must only be a portion of the control time or actual time of heat treatment. On analysing the holding conditions throughout the thermal process this is confirmed. The following were the times required for the milk to flow through the various sections while at the operating temperature:-

	Plate Arrangement A	Plate Arrangement B
Heater section	3.5 seconds	4.2 seconds
Holding tube	15.6 seconds	15.7 seconds
Flow diversion valve	7.0 seconds	7.0 seconds
Regenerator	0.3 seconds	0.8 seconds
Total	26.4 seconds	27.7 seconds

This is presented as further evidence that the holding time is only a portion of the actual time at the higher temperature. The phosphatase test, of course, is a measure of the total thermal treatment and thus with a control time of approximately 27 seconds it is expected that the desired inactivation to 2 units/0.5 ml milk would be attained at approximately 157.7°F.

(2) The Required Temperature-Time Combination

The results obtained on the rate of phosphatase destruction indicated that inactivation to 2 units/0.5 ml milk was reached at a temperature between 157° to 158°F., when the

holding time in the pasteurizer under study is 15 seconds. This temperature was verified by heat-treating each of 2 milks over the very narrow temperature range 157.3° to 158.1°F. The temperature was slowly raised through this range, samples for phosphatase tests being taken at regular intervals, and then lowered and the procedure was repeated. The results are reported in Table 8 and Figure 10 which shows inactivation at 157.6°F. The holding times in this series were in the range 16.19 to 16.28 seconds which is slightly longer than the previously reported average holding time of 15.57 seconds for 10 trials. From this observation it appears that when the pasteurizer is operated at a temperature of 160°-161°F. and a holding time of 15-16 seconds, as called for by different regulations, a considerable margin of safety is provided when reliance is placed on the phosphatase test.

To further illustrate the effect of heat-treatment on milk phosphatase the speed of the pasteurizer pump was increased to give various capacities above the normal capacity which gave a holding time of 15 seconds. The results of these flow-rate increases are recorded in Table 9 and Figure 11 and they show that inactivation was effected at a temperature of 159.7°F., when the holding time was only 10.85 seconds, i.e., the capacity of the pasteurizer could be increased 60% and still produce phosphatase negative milk. This observation not only lends weight to the accumulating evidence

that the so-called holding time is only a fraction of the total inactivating time but engenders greater confidence in this method of pasteurization.

In order to appreciate the thermal effect of the pasteurizer on milk phosphatase it is necessary to know the heat stability characteristics of the enzyme, in the range of HTST pasteurization. This problem was investigated by modifying the pasteurizer as previously noted. The shortest thermal treatment possible was provided by assembling a pipeline which lead directly from the outlet of the heater section to the inlet of the regenerative section. Then, in order to get varying conditions of time, this pipeline was increased. In all, seven different pipelines were assembled while the other conditions of heat-treatment were as heretofore noted. These pipelines provided control times of from 10.9 to 79.2 seconds. The effect of varying control time is indicated in Table 10, the units of phosphatase indicating the amount of active phosphatase present after the particular heat-treatment.

Since 2 units of phosphatase/0.5 ml milk represent phosphatase inactivation, the data in Table 10 were analysed to determine the conditions necessary for this destruction. Columns 2 and 3 of Table 11 contain the experimental measurements of the control time and temperature respectively at

which the phosphatase was inactivated to the required end point. However, the control time does not measure the inactivating effect of the heating-up and cooling intervals. The inactivating effect of these intervals was calculated by the method proposed by Ball (1943) and the results are shown in columns 4 and 5 of Table 11. The following equation, which is applicable to a semi-logarithmic heating rate and straight line cooling rate, was employed in this calculation:

$$t_{HBA} = U - \frac{0.01\ Bt_{RB}}{\log (HT - IT) + 1} - \frac{0.01\ A_c t_{cA}}{HT - FT}$$

where t_{HBA} = time milk is held at inactivation temperature, HT in seconds.

U = time necessary to inactivate phosphatase at holding temperature in seconds.

B and A_c = arbitrary constants.

t_{RB} = time consumed in rise of temperature of milk in seconds.

HT = holding temperatures of pasteurization process.

IT = initial temperature of milk.

FT = final temperature of milk after cooling.

The second and third terms in the right hand member of the equation express as equivalents the inactivating value of the heating-up and cooling intervals. Equivalent means the seconds of holding at the control temperature, HT, which would have the same inactivating effect.

In the application of this procedure to the sterilization of canned foods Ball uses the temperature of 170°F., which is 80°F. below the retort temperature, as the minimum lethal temperature. He stresses that a temperature having lethal effect should be selected, but it should be so chosen that only an insignificant lethal effect will occur at temperatures below it. In applying the method to the data of this investigation, the minimum holding temperature for LTLT pasteurization, 143°F., was selected as the initial and final temperature, as it satisfied these conditions. Arbitrary constants used in the equation were chosen according to the procedure outlined by Ball. The intervals t_{RB} and t_{cA} were measured on an enlargement of the heating-up and cooling divisions of Figure 6.

The heating-up equivalents for the intervals between 143°F. and the various inactivation temperatures, as tabulated in Table 11, illustrate clearly the importance of these intervals as the inactivation temperature approaches the region of HTST pasteurization. It is evident that at high temperatures, where the treatment time is short, the heating-up equivalent may account for a large percentage of the lethal or inactivating effect. The equivalent of the cooling interval indicates that its inactivating effect is of much less significance than that of the heating equivalent and also that its magnitude is quite uniform between 160.7°F. and 153.3°F.

The uniformity of the cooling equivalent in this narrow temperature range is understandable when the interval, only approximately one second because of the rapid straight line cooling, is considered. The summation of the control time and the heating-up and cooling equivalents is the inactivation time for each inactivation temperature. The values in the last column of Table 11 represent the inactivation time, at each temperature, if the heating-up and cooling were instantaneous. They are the values of U for each inactivation temperature.

In Figure 12, the U values are plotted on semi-logarithmic scale. The equation for this inactivation curve is:-

$$T = 171.84 - 9.66 \log t$$

where T = temperature in ^{o}F. and

t = time in seconds.

The Z value is $9.7^{o}F$. In Figure 13 this curve is shown by line A and is compared with curve B which is based on the control time only at each inactivation temperature and thus excludes the heating-up and cooling periods. Curve B is also a best fit line with the equation $T = 170.47 - 8.89 \log t$ and has a Z value of $8.9^{o}F$. These curves illustrate clearly the effect of the addition of the heating-up and cooling equivalents in the calculation of a phosphatase inactivation curve.

The straight-line course, as indicated in Figure 13, of the temperature-time inactivation curves conforms with results obtained by Sanders and Sager (1948). Holland and Dahlberg (1940), Kay and Graham (1935), Lear and Foster (1949) and Hetrick and Tracy (1948) also report a similar straight-line inactivation curve. The Z values for the curves produced by these various authors establishes a range of from 8.28°F. to 9°F. with Kay and Graham's the only deviation at Z = 11.7°F.

The 16.8 seconds required at 160°F. for inactivation is considerably less than that reported by several of the above mentioned authors. Most of the differences can be accounted for by the methods of analysis, the apparatus employed and the end point used to indicate inactivation. However, since Sanders and Sager employed similar methods of analysis and the same end point then some uniformity should exist. The fact that they require 24 seconds for inactivation at 160°F. is hardly in agreement with the 16.8 seconds established by this investigation. If an end point of 2 units of phosphatase/0.5 ml milk is used in the analysis of Hetrick and Tracy's (1948) results then approximately 15 seconds are required at 160°F. to produce the desired inactivation.

In Table 12 the percentage values of the inactivation effect of heating-up and cooling are summarized. These values were obtained by applying the following equations:-

$$p_B = \frac{Bt_{RB}}{U[\log (HT - IT) + 1]}$$

$$p_{cA} = \frac{A_c t_{cA}}{U(HT - FT)}$$

where p_B and p_{cA} = percentage of the required inactivating heat contributed by the heating-up and cooling intervals, respectively.

(3) Variability of Phosphatase Results

Two samples of heat treated milk were each analysed six times to determine the reliability of the phosphatase test. The following phosphatase concentrations were obtained:-

Milk #1	Milk #2
4.20 units/0.5 ml	3.96 units/0.5 ml
3.32 " " "	3.42 " " "
3.32 " " "	3.16 " " "
3.32 " " "	2.84 " " "
4.06 " " "	3.32 " " "
3.84 " " "	3.08 " " "

An analysis of these concentrations establishes the following results:-

	Milk #1	Milk #2
Average	3.68 units/0.5 ml	3.30 units/0.5 ml
Standard Deviation	0.37 " " "	0.36 " " "
Probable Error	±0.25 " " "	±0.23 " " "
Range of Variability	3.32-4.20 " "	2.84-3.96 " "

The data reported in Tables 6 and 7 were obtained under relatively similar conditions of heat treatment. Therefore, these 16 trials were each analysed for the temperature necessary to provide the desired inactivation. The last columns in Tables 6 and 7 contain the required inactivation temperatures for each trial. An analysis of these temperatures indicates the following results:-

Average	157.67°F.
Standard Deviation	0.20°F.
Probable Error	±0.13°F.
Range of Variability	157.36-158.00°F.

(e) Impairment of Creaming

(1) Rate of Destruction of Creaming Property

In order to determine the rate of cream volume destruction, under the conditions of plate arrangement A, the impairment of creaming was measured in the temperature range 155.8°F.-164.9°F. These measurements are reported in Table 13 where the creaming indexes for a series of trials with a holding time of 15 seconds are shown. For purposes of illustration the averages of the results are plotted graphically in Figure 14 which shows the decrease in creaming indexes. In this figure lines A and B represent 1 and 2 percent reductions in cream volume respectively.

The results show that there is a gradual decrease in the creaming index starting at the lowest temperature, 155.8°F. At 157.5°F. the cream volume has been reduced 1% and a cream volume reduction to a level of 2% does not take place until 160.1°F. is reached. However, it is doubtful if a cream volume reduction of 1 to 2 percent is commercially significant. According to Millenky and Bruechner (1941) a 2% reduction is insignificant commercially when 4% milk was compared in American quart bottles. Marquardt and Dahlberg (1931) report that a 0.2 change in the creaming index is significant for experimental conditions. Holland and Dahlberg (1940) used an end point of 1% change in the cream volume. However, they stress that such a change would not be detectable by the consumer.

The nature of the curve in Figure 14 seemed to indicate that the rate of destruction of creaming property, as illustrated by the creaming indexes, does not decrease at a constant rate. Therefore, the data used to construct Figure 14 were plotted on semi-logarithmic paper and the resulting curve is shown in Figure 15. With the exception of 155.8°F., the changes in creaming indexes form a straight line relationship with changing temperatures, when the holding time is 15 seconds.

The small change at 155.8°F. may have been due to factors other than heat affecting the creaming property of the milk.

Between the relatively high temperatures of 156.8°F. and 164.9°F. the influence of heat, on the destruction of creaming property, appears to proceed at a rate comparable to that of a monomolecular reaction.

(2) The Required Temperature-Time Combination

The impairment of creaming in the temperature range of HTST pasteurization, was investigated at the same time as phosphatase was being studied. Thus the pasteurizer modifications previously noted are also applicable to the data on creaming. The effect of varying control time and temperature on the cream volume is indicated in Table 14. Since a change of 1% in the cream volume has been chosen to indicate significant destruction the data in Table 14 were analysed to determine the conditions necessary for this destruction. Columns 2 and 3 of Table 15 contain the experimental measurements of the control time and temperature respectively at which the creaming was destroyed to the selected end point. However, as already noted under Inactivation of Phosphatase, the control time does not measure the inactivating or destructive effect of the heating-up and cooling intervals. The destructive effect of these intervals on creaming was calculated by Ball's method (1943), which has already been used in reporting phosphatase destruction. The calculated results for heating-up and cooling, expressed as equivalents, are shown in columns 4 and 5 of Table 15. These equivalents

again illustrate clearly the importance of the heating-up and cooling intervals as the temperature approaches the region of HTST pasteurization.

The values in the last column of Table 15 represent the destruction times, at each temperature, if the heating-up and cooling were instantaneous. They are the values of U for each temperature and in Figure 16 these values are plotted on semi-logarithmic graph paper. The equation for this destruction curve is:-

$$T = 174.60 - 12.41 \log t$$

where T = temperature in °F. and

t = time in seconds

The Z value of this curve is 12.4°F. In Figure 17 this curve is shown by line A and is compared with curve B which is based on the control time only at each destruction temperature and thus excludes the heating-up and cooling periods. Curve B is also a best fit line with the equation $T = 172.93 - 11.49 \log t$ and has a Z value of 11.5°F. These curves illustrate clearly the effect of the addition of the heating-up and cooling equivalents in the calculation of a destruction curve. Figure 16 establishes that 15.02 seconds are required at 160°F. for destruction of creaming property. This is considerably less than the following reported observations:-

Holland and Dahlberg (1940)	24.6 seconds
Marquardt and Dahlberg (1931)	22.2 seconds
Dahlberg (1932)	19.8 seconds

(3) Variability of Creaming Results

In order to determine the reliability of the method used for determining cream volume, 12 replicas of one sample of milk were measured. The following cream volumes were obtained:-

9.75 ml	9.75 ml
9.75 ml	10.00 ml
9.75 ml	9.75 ml
9.75 ml	10.00 ml
10.00 ml	9.75 ml
9.75 ml	9.75 ml

An analysis of these measurements establishes the following results:-

Average	9.81 ml
Standard Deviation	0.11 ml
Probable Error	±0.07 ml
Range of Variability	9.75 - 10.00 ml

Under conditions of plate arrangement A and B and 15 seconds holding time, the following temperatures were required to produce the desired change of 1 per cent in the cream volume:-

Plate Arrangement A		Plate Arrangement B	
Trial No.	Temperature °F.	Trial No.	Temperature °F.
4	157.1	9	155.9
5	157.3	10	155.9
6	156.7	20	155.9
7	156.6	21	157.0
10	155.8	22	155.9
12	159.0	23	156.5
13	157.2	24	157.2
21	158.7		
22	158.4		

An analysis of these temperatures establishes the following results:-

Average	156.9°F.
Standard Deviation	1.0°F.
Probable Error	±0.7°F.
Range of Variability	155.8 - 159.0°F.

DISCUSSION

HTST pasteurization is enveloped in not a little confusion resulting from ignorance of the precise thermal death time of the tubercle organism at the higher temperatures. When 160°F. for 15 seconds is adopted as a standard, a reasonable factor of safety above the thermal death time of M. tuberculosis is presumably included. But there is still a disturbing element of conjecture about the lethal properties of heat in relation to the tubercle organism at this temperature. The extent of the supposed factor of safety is, therefore, unknown.

Although a number of investigators have studied phosphatase inactivation and destruction of creaming property at the higher temperatures, the results are conflicting. Not only are different temperature-time combinations reported but the Z values of the inactivation and destruction curves vary. Most of the studies are based on heat-treatment of milk in laboratory apparatus of the immersed coil type which generally have several disadvantages.

The plate-type HTST pasteurizer used in this investigation offers certain advantages over the laboratory-type heat-exchanger but has the disadvantage of fairly long heating-up and cooling periods. This is, however, off-set by the ease with which accurate temperature and time measurements may

be made at will at any point throughout the apparatus and tends to be minimized if the effect of heating-up and cooling can be accurately calculated. Further, this pasteurizer is comparable to other larger commercial pasteurizers and, therefore, most of the results are probably indicative of commercial HTST pasteurization.

The various sections of the HTST pasteurizer studied offer many possibilities for entrapping air. It seems probable that these air locks may influence the control time in a manner similar to their effect on the holding time. Further, the timing of these machines, by the salt conductivity method, necessitates measurements being made on water and then calculating the corresponding time for milk by observing the milk-water ratio which does not appear to be constant under relatively similar conditions. There is no purpose in specifying a holding time unless it is maintained. Its maintenance is assured only if air is not permitted to be entrapped in the holding tube. This and other investigations have shown that entrapped air not only shortens the holding time but gives it an unpredictable variability. A sloping holding tube can prevent air locks in this section thereby eliminating its influence on holding time. This point receives heavy emphasis in American control of HTST pasteurization but appears to be largely ignored in Canada. It would seem that more rigid control of the slope and timing of holding tubes is desirable in this country.

The fact that phosphatase is not inactivated at 160°F. for 15 seconds while these pasteurizers turn out a phosphatase negative milk simply means that the holding time is only a portion of the total time of heat-treatment at temperatures sufficiently high to inactivate the enzyme. The total pasteurizing or control time is, therefore, of great importance. Figures 5 and 6 establish that the holding time for the pasteurizer under investigation is only 59.9% and 56.8%, respectively, of the control time. The phosphatase test is a measure of this control time plus the inactivating effect of the heating-up and cooling intervals, not a measure of the holding time alone. The fact that the holding time is only a portion of the control time is further illustrated by the fact that the experimental pasteurizer could be operated at 60% above its rated capacity and still produce phosphatase negative milk.

Although fairly sensitive methods of measuring for phosphatase have been devised, no comparable method has as yet been introduced to determine cream volume impairment. The method of measuring cream volumes in graduated cylinders offers only a relative comparison to the more accurate procedure used for phosphatase determinations. However, results established by this investigation indicate that destruction of creaming property is similar to the effect of heat on phosphatase. Therefore, in the range of temperatures employed

in HTST pasteurization, some destructive effect must have been contributed by the heating-up and cooling periods in a manner similar to their effect on phosphatase.

In Figure 18 curves A and B represent the temperature-time relationships for phosphatase inactivation and impairment of creaming, respectively. These curves indicate that at temperatures below 162.2°F. the creaming property of milk is destroyed before phosphatase is inactivated and the Z value for creaming impairment is greater than the Z value for phosphatase inactivation. At 160°F. 16.8 seconds are required to inactivate phosphatase to the desired end point, while 15.0 seconds at the same temperature are required for the specified impairment of creaming property. These values tend to be considerably lower than the corresponding values reported in the literature.

Tables 12 and 16 establish that at the temperature of HTST pasteurization considerable heat effect is attributed to the heating-up and cooling intervals. For phosphatase these intervals combined provided 16.93% of the total inactivating time at 160.7°F. and decreases to only 0.81% at 153.3°F. For creaming impairment the figures are 18.19% at 160.1°F. and 0.96% at 151.3°F.

In order to insure a minimum temperature of 161°F. in HTST pasteurization the flow diversion valve is usually set to divert when the temperature drops below 161.5°F. Therefore, it is necessary in practice to operate the pasteurizer

sufficiently in excess of this temperature to avoid frequent diversion valve operation. At 161.5°F. the data in Table 17 show times of 11.7 and 11.3 seconds required for inactivation and destruction of phosphatase and creaming property respectively. The control time, symbol G, Figure 6, is 27.7 seconds when the holding time is 15.7 seconds. The addition of the heating-up and cooling equivalents would give a time of approximately 30 seconds at the control temperature, 161.5°F. The HTST pasteurizer studied in this report, therefore, provides a heat-treatment considerably in excess of a minimum standard of 161°F. for 15 seconds.

The weight of evidence presented in this report is, that, within the temperature range investigated in the experimental pasteurizer, M. tuberculosis would be killed before phosphatase is inactivated. Thus, it might appear that the phosphatase test is an adequate sole control of the process. However, the phosphatase test is insensitive to minute amounts of raw milk and its performance should be the responsibility of a trained chemist. In consequence, there would seem to be good reason for a specified holding time of 15 seconds at 161°F. but little evidence to substantiate increasing this to 16 seconds at the same time.

The fact that creaming property is impaired before phosphatase inactivation forces the operator to adopt an arbitrary reduction value as being commercially insignificant. Such a value will vary with such things as the type and

composition of the product, the market requirements and the final container, and can be determined only by the trial and error method. The problem is, therefore, complex and it is doubtful if it can be used as a satisfactory field control of HTST pasteurization.

SUMMARY AND CONCLUSIONS

As a result of this study the following conclusions apply to the pasteurizer studied:

1. When the HTST pasteurizer was operated under conditions giving 15.6 seconds holding time phosphatase was inactivated at 157.7°F. Increasing the capacity 60% still produced phosphatase negative milk when operating at 160°F.
2. The thermal treatment provided by the holding tube in the HTST pasteurizer studied is only approximately 50% of the total thermal treatment provided.
3. The Z value of the phosphatase inactivation curve, including the evaluation of the effect of the heating-up and cooling intervals, is 9.7°F. which is outside the range of Z values previously reported. Exclusive of this effect the Z value is 8.9°F. which is within the range of those Z values previously reported.

4. Phosphatase cannot be inactivated without an accompanying creaming impairment. Inactivation can be effected, however, without a creaming loss that is commercially prohibitive.

5. The Z value of the impairment of creaming curve, including the evaluation of the effect of the heating-up and cooling intervals, is 12.4°F. Exclusive of this effect the Z value is 11.5°F.

6. At 161°F., the present legal minimum for HTST pasteurization in seven Canadian provinces, phosphatase is inactivated in 13.3 seconds while the cream volume is impaired in 12.5 seconds. At 160°F. the corresponding times are 16.8 seconds and 15.0 seconds.

7. (a) The heating-up interval from 143°F. to 160°F. is 3.4 seconds. The thermal effect of this interval on phosphatase inactivation is equivalent to 2.0 seconds at 160°F. and it accounts for 12.16 percent of the inactivation time at this temperature. At 152°F. the equivalent effect of the heating-up interval is 0.4 seconds and this represents only 0.4 percent of the inactivation time.

   (b) For impairment of creaming the heating-up interval to 160°F. is equivalent to 2.2 seconds and it accounts for 14.66% of the destruction time at this temperature.

At 152°F. the corresponding data are 0.44 seconds and 0.7 percent.

8. (a) For phosphatase inactivation the cooling interval from 160°F. to 143°F. is the equivalent of 0.19 seconds at 160°F. accounting for only 1.18 percent of the inactivating time at this temperature. At 152°F. the equivalent effect of the cooling interval is 0.18 seconds and this represents only 0.2 percent of the inactivation time.

(b) For impairment of creaming this interval is equivalent to 0.3 seconds at 160°F. and it accounts for only 1.64 percent of the destruction time at this temperature. At 152°F. the corresponding data are 0.3 seconds and 0.4 percent.

9. Entrapped air in the holding tube leads to varied but shortened holding times.

10. Since the water-milk ratio is not constant under relatively similar conditions, it is necessary to determine the ratio for each trial when calculating milk holding times from the corresponding water measurements determined by the salt conductivity method.

11. There are objections to the use of the phosphatase test as the sole field control of HTST pasteurization. There appears to be justification for a specified minimum

holding time of 15 seconds at a minimum of 160°F.

12. The measurement of cream volume destruction does not provide a satisfactory criterion of pasteurization.

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TABLES AND FIGURES

Table 1

Comparisons of pump capacity with milk and water*

Trial No.	Pump Capacity Water G.P.H.	Pump Capacity Milk G.P.H.	Increases Milk over Water Percent
26	138.4	145.4	5.1
25	131.0	138.6	5.8
24	123.0	130.7	6.3
17	116.0	126.9	9.4
18	108.0	117.2	8.5
19	100.0	112.4	12.4
2	93.0	104.1	11.9
20	92.1	105.1	14.2
3	88.2	100.6	14.1
7	84.6	97.1	14.8
12	79.8	92.4	15.8
16	76.8	88.4	16.7
15	75.6	88.4	16.9
9	72.0	84.3	17.1

*Plate arrangement A.

Table 2

Comparisons of pump capacity with milk and water*

Trial No.	Pump Capacity Water G.P.H.	Pump Capacity Milk G.P.H.	Increases Milk over Water Percent
1	81.6	91.5	12.1
2	81.6	96.5	18.3
3	81.6	93.0	14.0
4	81.6	93.0	14.0
5	81.6	92.8	13.7
6	81.6	93.4	14.5
7	81.6	93.4	14.5
8	81.6	93.8	15.0
9	81.6	93.8	15.0
10	81.6	94.4	15.7
11	81.6	94.2	15.4
12	81.6	95.4	16.9
13	81.6	94.8	16.2
14	81.6	94.5	15.8
15	81.6	94.2	15.4
16	81.6	95.2	16.7
17	82.2	93.6	13.9
18	81.6	96.8	18.6
19	81.6	90.1	10.4
20	81.6	96.9	18.8
21	81.6	98.8	21.1
22	81.6	93.0	14.0
23	81.6	93.1	14.1
24	81.6	91.9	12.6

*Plate arrangement B.

Table 3

Internal Timing Measurements

	Plate Arrangement A		Plate Arrangement B	
	Water	Milk*	Water	Milk**
Regenerator (raw milk side)	10.0 sec.	8.7 sec.	5.2 sec.	4.5 sec.
Filtering and Pumping	9.8 "	8.5 "	9.8 "	8.5 "
140°F. to end of heater	6.2 "	5.4 "	8.8 "	7.8 "
160°F. to end of heater	4.0 "	3.5 "	4.8 "	4.2 "
Heater	7.0 "	6.1 "	10.6 "	9.2 "
Holding tube	18.0 "	15.7 "	18.2 "	15.8 "
End of Holding Tube to Regenerator Section	8.0 "	7.0 "	8.0 "	7.0 "
End of Holding Tube to end of 160°F.	8.4 "	7.3 "	8.8 "	7.8 "
End of Holding Tube to end of 140°F.	12.0 "	10.4 "	9.6 "	8.3 "
Regenerator (pasteurized milk side)	10.0 "	8.7 "	5.2 "	4.5 "

*Water flow 87.0% of milk flow.
**Water flow 87.1% of milk flow.

Table 4

Measured flow time with varying holding tube lengths with plate arrangement B

Trial Run #	Time in Heater	Measured Pipe-line Time	Time in Regenerator	Control Times Water	Milk
3	4.8 sec.	6.8 sec.	0.8 sec.	12.4 sec.	10.9 sec.
4	4.8 "	6.8 "	0.8 "	12.4 "	10.9 "
5	4.8 "	14.1 "	0.8 "	19.7 "	17.3 "
6	4.8 "	14.1 "	0.8 "	19.7 "	17.2 "
7	4.8 "	21.8 "	0.8 "	27.4 "	23.9 "
8	4.8 "	21.5 "	0.8 "	27.1 "	23.6 "
9	4.8 "	27.2 "	0.8 "	32.8 "	28.5 "
10	4.8 "	27.0 "	0.8 "	32.6 "	28.2 "
11	4.8 "	39.0 "	0.8 "	44.6 "	38.7 "
12	4.8 "	39.2 "	0.8 "	44.8 "	38.3 "
13	4.8 "	16.4 "	0.8 "	22.0 "	18.9 "
14	4.8 "	16.7 "	0.8 "	22.3 "	19.3 "
15	4.8 "	65.4 "	0.8 "	71.0 "	61.5 "
16	4.8 "	65.4 "	0.8 "	71.0 "	60.9 "
17	4.8 "	80.8 "	0.8 "	86.4 "	75.9 "
18	4.8 "	81.3 "	0.8 "	86.9 "	73.3 "
19	4.8 "	81.8 "	0.8 "	87.4 "	79.2 "

Table 5

Destruction of milk phosphatase using plate arrangement B

Trial No.	Control Time in Seconds	Units of phosphatase/0.5 ml milk at 158.5°F.	Units of phosphatase/0.5 ml milk at 160.1°F.
3	10.9	-	4.08
4	10.9	-	3.22
5	17.3	5.60	0.92
6	17.2	6.56	1.12
7	23.9	2.76	0.67
8	23.9	2.72	0.56
9	28.5	0.68	0.18
10	28.2	0.72	0.24
11	38.6	0.24	-
12	38.3	0.28	-
13	18.9	5.60	0.96
14	19.3	5.28	1.40

Table 6

Destruction of milk phosphatase with plate arrangement A

Trial Numbers	Holding Time Seconds	Temperature °F. 156.3	156.8	157.3	157.8	158.3	158.7	159.2	159.7	Inactivation Point °F.
		Units of Phosphatase/0.5 ml Milk								
1	15.15	7.24	4.50	2.43	1.76	0.71	0.71	0.04	0.14	157.60
4	15.30	>8.00	7.20	4.24	2.44	1.28	0.76	0.28	0.29	157.95
5	15.89	7.34	5.00	2.48	1.56	0.68	0.60	0.72	0.20	157.50
6	15.41	>8.00	6.48	4.40	2.68	1.27	0.72	0.74	0.60	158.00
7	15.67	7.24	5.20	2.52	1.72	0.56	0.00	0.24	0.00	157.60
10	15.69	4.27	3.16	2.11	1.48	0.59	0.00	0.00	0.00	157.38
12	15.85	7.68	4.68	2.88	1.72	1.26	1.08	0.52	0.52	157.66
13	15.70	5.76	3.20	2.12	1.28	0.52	0.76	0.00	0.00	157.36
21	15.33	>8.00	7.13	3.96	2.40	1.48	1.24	0.96	0.96	158.00
22	15.75	>8.00	7.20	2.96	1.60	1.06	0.50	0.45	0.18	157.62
Average	15.57	---	5.18	3.01	1.86	0.94	0.64	0.40	0.29	

Table 7

Destruction of milk phosphatase with plate arrangement B

Trial Number	Holding Time Seconds	Temperature °F. 156.5	157.0	157.5	157.9	158.5	159.0	159.6	160.1	Inactivation Point °F.
		Units of phosphatase/0.5 ml milk								
9	16.0	8.04	3.94	2.16	1.52	0.68	0.48	0.36	0.18	157.60
10	15.9	5.16	3.24	2.00	1.32	0.72	0.62	0.28	0.24	157.50
20	15.2	8.92	5.12	3.08	1.76	0.96	0.68	0.61	0.49	157.80
21	15.1	8.08	5.12	2.88	2.12	1.00	0.80	0.56	0.48	157.96
22	16.1	5.88	4.04	2.40	1.64	1.02	0.92	0.71	0.56	157.68
24	16.1	5.88	3.52	2.12	1.32	0.96	0.71	0.26	0.20	157.56
Average	15.73	6.99	4.16	2.44	1.61	0.89	0.70	0.46	0.36	

Table 8

Destruction of milk phosphatase with plate arrangement A

Trial Number	Sample Number	Temperature °F. 157.3	157.5	157.7	157.9	158.1
		Units phosphatase/0.5 ml milk				
15	1	3.76	2.68	1.96	1.92	1.32
	2	3.72	2.42	1.72	1.32	1.20
	3	2.32	2.68	1.63	1.15	0.96
	4	1.84	1.96	1.32	1.27	1.32
16	1	2.63	2.35	1.92	2.00	1.12
	2	3.18	2.76	2.04	1.92	1.32
	3	3.16	2.52	2.32	1.51	1.24
Average		2.93	2.48	1.84	1.58	1.21

Table 9

The effect of rate of flow on destruction of milk phosphatase

Trial Number	Flow Rate Increase Percent	Holding Time Seconds	Temperature °F. 156.8	157.3	157.8	158.3	158.7	159.2	159.7
			Units of Phosphatase/0.5 ml Milk						
13	Normal	15.70	3.20	2.12	1.28	0.52	0.76	0.07	0.00
22	Normal	15.75	5.20	2.96	1.60	1.06	0.50	0.43	0.18
21	6.7	15.33	7.13	3.96	2.40	1.48	1.24	0.91	0.96
23	15.5	13.54	7.92	5.45	3.24	1.63	1.06	0.64	0.08
19	23.5	12.99	>8.00	>8.00	5.16	2.32	1.51	1.20	0.74
18	28.8	12.97	>8.00	6.79	4.88	2.65	1.67	0.79	0.12
17	39.5	12.07	>8.00	>8.00	6.07	4.16	1.67	0.67	0.53
24	43.6	11.67	>8.00	>8.00	>8.20	4.90	3.38	1.63	1.06
25	52.3	11.15	>8.00	>8.00	>8.00	7.03	3.84	2.40	1.44
26	59.8	10.85	>8.00	>8.00	>8.00	>8.00	6.13	2.92	1.76

Table 10

The effect of varying control time and temperature on the destruction of phosphatase

Trial No.	Control Time Seconds	Temperature °F.																							
		151.3	151.7	152.4	153.0	153.5	153.9	154.4	155.0	155.5	155.9	156.5	157.0	157.5	157.9	158.5	159.0	159.6	160.1	160.6	161.0	161.6	162.1	162.7	163.0	163.6	164.1
		Units phosphatase/0.5 ml milk																									
3	10.9																10.68	6.48	4.08	2.32	1.50	0.74	0.64	0.44	0.50	0.44	0.24
4	10.9																7.92	5.08	3.22	2.36	1.80	1.16	0.72	0.73	0.50	0.50	0.42
5	17.3														9.90	5.60	2.60	1.16	0.92	0.60	0.42	0.30	0.28	0.28	0.08	0.08	0.10
6	17.2															6.56	2.77	1.96	1.12	1.08	0.66	0.44					
7	23.9													7.56	4.60	2.76	1.60	1.00	0.67	0.52	0.40						
8	23.9												10.00	5.76	4.56	2.72	1.48	0.64	0.56	0.24	0.22						
9	28.5											8.04	3.94	2.16	1.52	0.68	0.48	0.36	0.18								
10	28.2										8.12	5.16	3.24	2.00	1.32	0.72	0.62	0.28	0.24								
11	38.6								5.52	3.24	2.86	1.48	0.96	0.72	0.36	0.24	0.28										
12	38.3								4.72	2.96	2.20	1.56	0.84	0.68	0.52	0.28	0.24										
13	18.9													10.68	8.23	5.60	2.88	1.52	0.96	0.48	0.56						
14	19.3														9.56	5.28	3.60	2.24	1.40	1.08	0.56						
15	61.5				9.72	5.68	4.12	2.52	1.40	1.20	0.84	0.64	0.52														
16	60.9				9.72	5.84	4.56	2.32	1.44	0.56	0.40	0.12	0.16														
17	75.9		8.20	4.12	2.88	1.44	1.08	0.68	0.52	0.38	0.20																
18	73.3		9.24	7.56	4.68	3.00	2.04	1.44	1.28	1.26	1.08																
19	79.2	10.08	7.44	4.20	2.64	1.48	0.96	0.64	0.48	0.26	0.40																

Table 11

Inactivation temperature-time combinations

Trial No.	Control Time Seconds	Inactivation at °F.	Heating up Equivalent Seconds	Cooling Equivalent Seconds	Total Inactivation Time Seconds
3	10.9	160.7	2.0	0.19	13.1
4	10.9	160.7	2.0	0.19	13.1
14	19.3	159.7	1.7	0.19	21.2
6	17.2	159.5	1.6	0.19	19.0
13	18.9	159.3	1.5	0.19	20.6
5	17.3	159.2	1.5	0.19	19.0
8	23.6	158.7	1.2	0.19	25.0
7	23.9	158.7	1.2	0.19	25.3
10	28.2	157.5	0.9	0.19	29.3
9	28.5	157.6	0.9	0.19	29.6
12	38.3	156.1	0.7	0.19	39.2
11	38.7	156.2	0.7	0.19	39.6
16	60.9	154.6	0.6	0.19	61.7
15	61.5	154.7	0.6	0.19	62.3
18	73.3	154.0	0.5	0.19	74.0
19	79.2	153.3	0.5	0.18	79.9

Table 12

Heating and cooling effect as percentage of total inactivation time

Trial No.	Inactivation at °F.	Total Inactivation Time Seconds	Heating up Percent	Cooling Percent	Heating and Cooling Percent
3	160.7	13.1	15.47	1.46	16.93
4	160.7	13.1	15.47	1.46	16.93
14	159.7	21.2	7.96	0.97	8.93
6	159.5	19.0	8.27	1.08	9.35
13	159.3	20.6	7.06	1.01	8.07
5	159.2	19.0	8.27	1.09	9.36
8	158.7	25.0	4.88	0.79	5.67
7	158.7	25.3	4.83	0.78	5.61
10	157.5	29.3	3.18	0.71	3.89
9	157.6	29.6	3.14	0.70	3.84
12	156.1	39.2	1.78	0.51	2.29
11	156.2	39.6	1.76	0.53	2.29
16	154.6	61.7	0.95	0.32	1.27
15	154.7	62.3	0.93	0.31	1.24
18	154.0	74.0	0.71	0.28	0.99
19	153.3	79.9	0.58	0.23	0.81

Table 13

The creaming of milk heat-treated in HTST pasteurizer with plate arrangement A

Trial Number	Holding Time Seconds	Control	Temperature °F.									
			155.8	156.8	157.8	158.7	159.7	160.7	161.8	162.9	163.8	164.9
			24 hr. - Creaming Index									
4	15.30	4.30	4.06	4.06	3.83	3.64	3.67	3.36	3.13	2.89	2.66	1.80
5	15.89	3.78	3.64	3.56	3.41	3.33	3.26	3.07	2.80	2.50	2.12	1.40
6	15.41	4.38	4.30	4.03	4.06	3.91	3.64	3.55	3.28	3.13	2.42	1.88
7	15.67	4.03	4.06	4.06	3.98	3.64	3.59	3.36	3.14	2.58	2.19	1.56
10	15.69	4.25	3.83	3.75	3.67	3.67	3.58	3.37	3.08	2.92	2.67	2.08
12	15.85	4.06	4.06	3.91	3.83	3.83	3.59	3.52	3.28	2.97	2.42	1.88
13	15.70	4.33	4.25	4.08	3.92	3.92	3.75	3.67	-	-	-	-
21	15.33	4.19	4.11	3.95	3.95	3.87	3.67	3.15	3.31	2.95	2.74	2.10
22	15.75	4.19	4.19	4.03	3.79	3.79	3.67	3.51	3.23	2.90	2.50	1.69
Average	15.62	4.17	4.06	3.92	3.83	3.73	3.60	3.40	3.16	2.86	2.47	1.80

Average fat content of milk - 3.14%

Table 14

The effect of varying control time and temperature on cream volume

Control Time Seconds	Temperature °F.																									Percent Butterfa
	Control	151.3	151.7	152.4	153.0	153.5	153.9	154.4	155.0	155.5	155.9	156.5	157.0	157.5	157.9	158.5	159.0	159.6	160.1	160.6	161.0	161.6	162.1	162.7	163.0	163.8	164.1	
	Percent Cream Volume																											
10.9	12														11½	11¼	11¼	11	11	11	11	11	10¾	10¾	10½	10	10	3.2
10.9	14														13½	13½	13½	13¼	13	13	13	12¼	12	12	11¾	11½	11	3.4
17.3	13½														12¾	12½	12½	12¼	12¼	12	12	11¾	11¾	11¾	11¾	11¾	11¾	3.3
17.2	14½														14	14	14	13½	13¾	13½	13¼	13	13	13	13	12¾	12½	3.4
23.9	14¼												13½	13¼	13¼	13¼	13	12¾	12¾	12½	12	12	11¾	11¾	11½			3.3
23.9	14½												14	13½	13¼	13	13	13	12½	12¼	12¼	12	12	11½	11½			3.3
28.5	14										13	12¾	12¾	12¼	12¼	12	11¾	11¾	11½	11¼	11	10¾	10¾					3.2
28.2	14¼										13	12¾	12½	12½	12½	12½	12¼	12	11¾	11½	11¼	11	10½					3.2
38.6	12½								11¾	11⅛	11¼	11¼	11	11	10¾	10¼	10	10	9¾	9¾	9½							3.0
38.3	14								13	13	13	12½	12¼	12	12	11¾	11¾	11⅛	11	11	11							3.3
18.9	15½												15	15	14¾	14½	14¼	14	13¾	13½	13½	13¼	13¼	12¾	12¾			3.8
19.3	13½												12¾	12¾	12¾	12¾	12½	12½	12½	12½	12	12	12	12	12			3.2
61.5	14	13¼	13	12½	12¼	12	12	12	12	11¾	11¾	11½	11½															3.2
60.9	12½		11¾	11¼	11	11	11	11	10¾	10½	10¼	10¼	10	10	9¾													2.9
75.9	14		12¾	12¾	12½	12	12	12	11½	11¼	11¼	11¼	11	11	11													3.0
73.3	15½	14½	14¼	14	14	13¾	13¾	13⅛	13	13	12¾	12½	12⅛															3.8
79.2	13	12	11¾	11½	11½	11	11	11	11	11	11	11	10¼															3.0

Table 15

Creaming destruction temperature-time conditions

Trial No.	Control Time Seconds	Destruction at °F.	Heating up Equivalent Seconds	Cooling Equivalent Seconds	Total Destruction Time Seconds
3	10.9	159.6	1.8	0.3	13.0
4	10.9	160.1	2.2	0.3	13.4
14	19.3	159.0	1.4	0.3	21.0
6	17.2	159.6	1.8	0.3	19.3
13	18.9	158.5	1.2	0.2	20.3
5	17.3	158.5	1.2	0.2	18.7
8	23.6	157.5	1.0	0.2	24.8
7	23.9	157.5	1.0	0.2	25.1
10	28.2	155.9	0.8	0.3	29.3
9	28.5	155.9	0.8	0.3	29.6
12	38.3	155.0	0.6	0.2	39.1
11	38.7	155.5	0.6	0.2	39.5
16	60.9	152.1	0.5	0.3	61.7
15	61.5	151.7	0.5	0.3	62.3
18	73.3	151.3	0.5	0.3	74.1
17	75.9	151.7	0.5	0.3	76.7
19	79.2	151.3	0.5	0.3	80.0

Table 16

Heating and cooling effect as percentage of total destruction time

Trial No.	Destruction at °F.	Total Destruction Time Seconds	Heating up Percent	Cooling Percent	Heating & Cooling Percent
3	159.6	13.0	13.47	1.94	15.41
4	160.1	13.4	16.36	1.83	18.19
14	159.0	21.0	6.84	1.17	8.01
6	159.6	19.3	9.07	1.31	10.38
13	158.5	20.3	6.15	1.18	7.33
5	158.5	18.7	6.68	1.28	7.96
8	157.5	24.8	4.03	0.91	4.94
7	157.5	25.1	4.04	0.90	4.94
10	155.9	29.3	2.56	0.86	3.42
9	155.9	29.6	2.54	0.85	3.39
12	155.0	39.1	1.42	0.60	2.02
11	155.5	39.5	1.56	0.57	2.13
16	152.1	61.7	0.83	0.41	1.24
15	151.7	62.3	0.83	0.43	1.26
18	151.3	74.1	0.61	0.38	0.99
17	151.7	76.7	0.68	0.35	1.03
19	151.3	80.0	0.58	0.35	0.93

Table 17

Temperature-time combinations for phosphatase inactivation and creaming impairment

Temperature °F.	Time Required to Inactivate Phosphatase	Time Required to Impair Creaming
	Seconds	Seconds
159.5	18.9	16.5
160.0	16.8	15.0
160.5	14.9	13.7
161.0	13.3	12.5
161.5	11.7	11.3
162.0	10.4	10.2

Figure 1

The HTST Pasteurizer

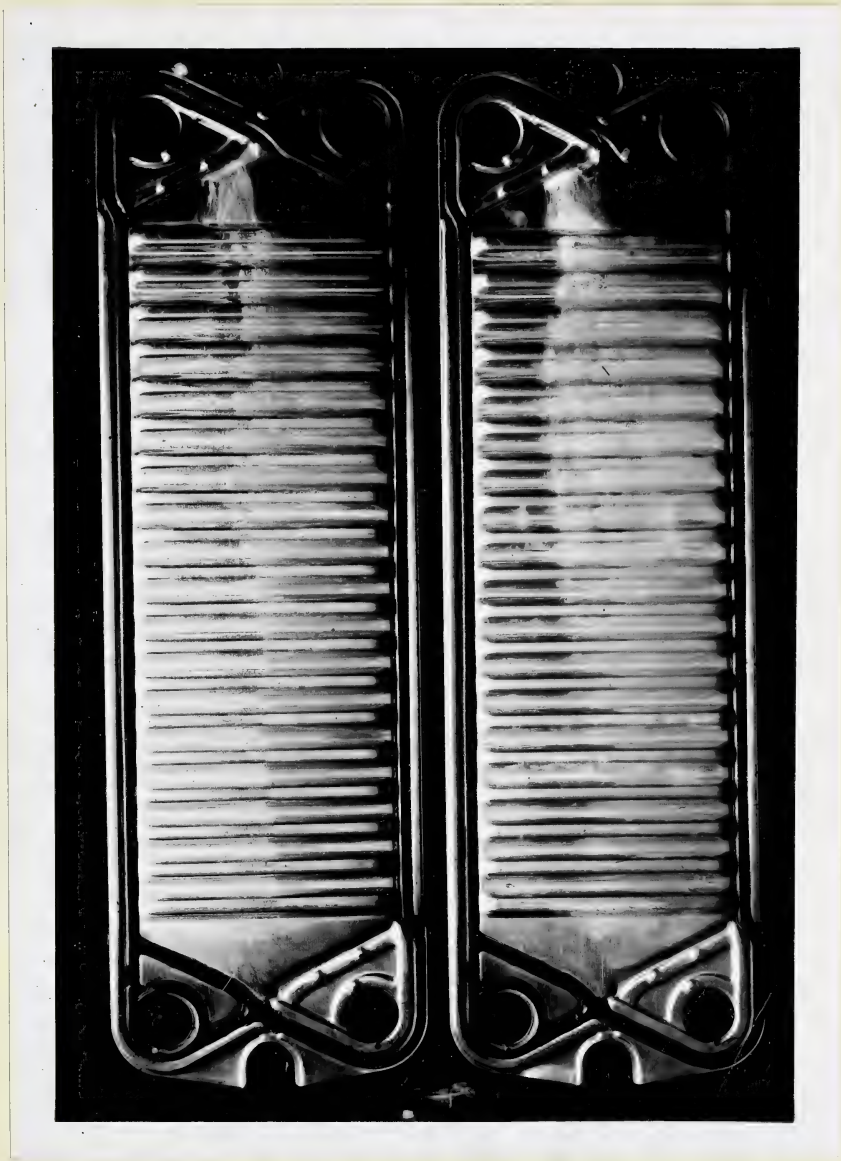

Figure 2

Plates showing the effect of entrapped air on milk flow pattern

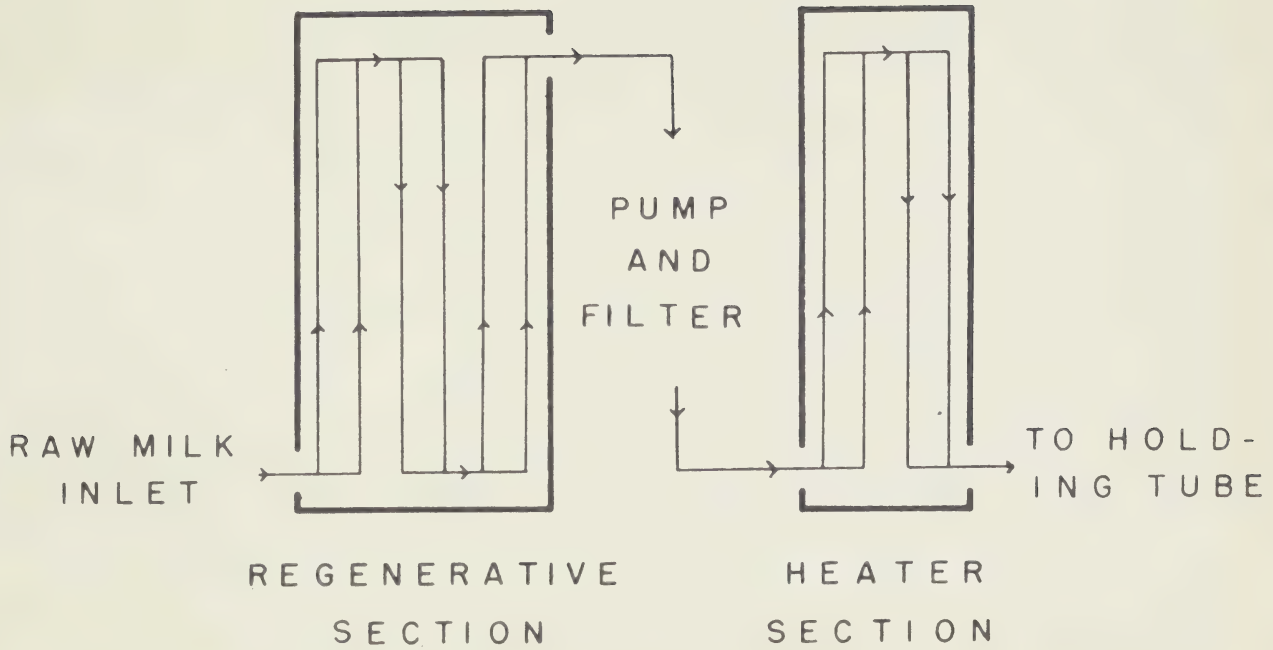

Figure 3

Flow diagram for plate arrangement A

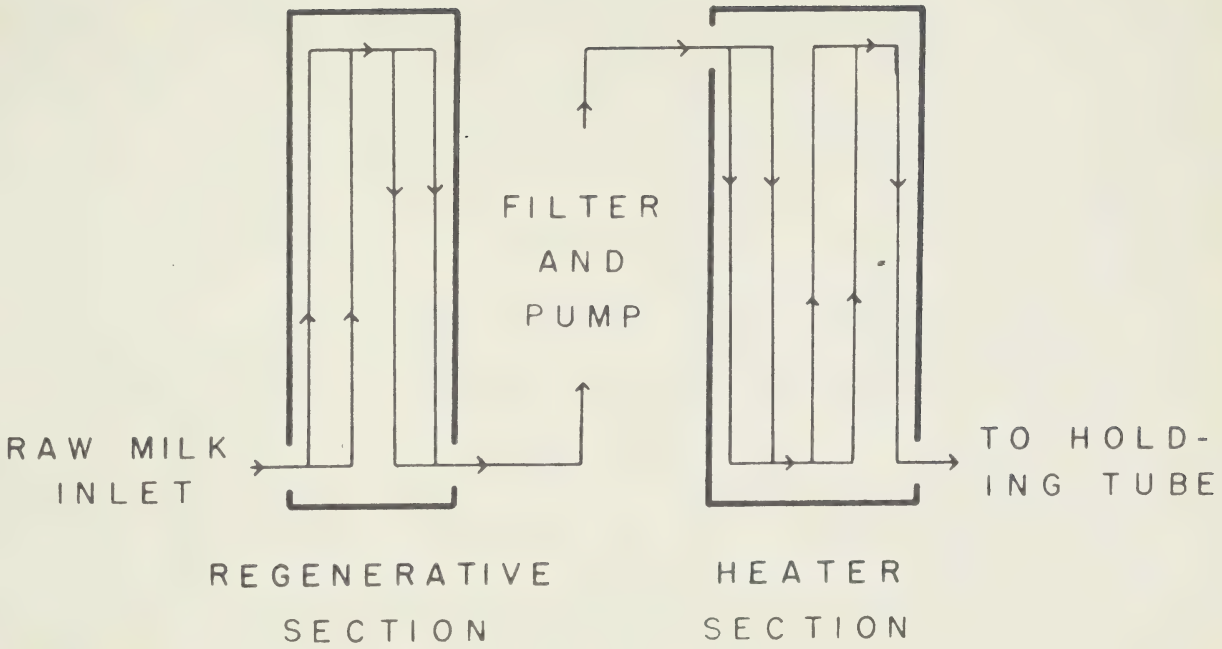

Figure 4

Flow diagram for plate arrangement B

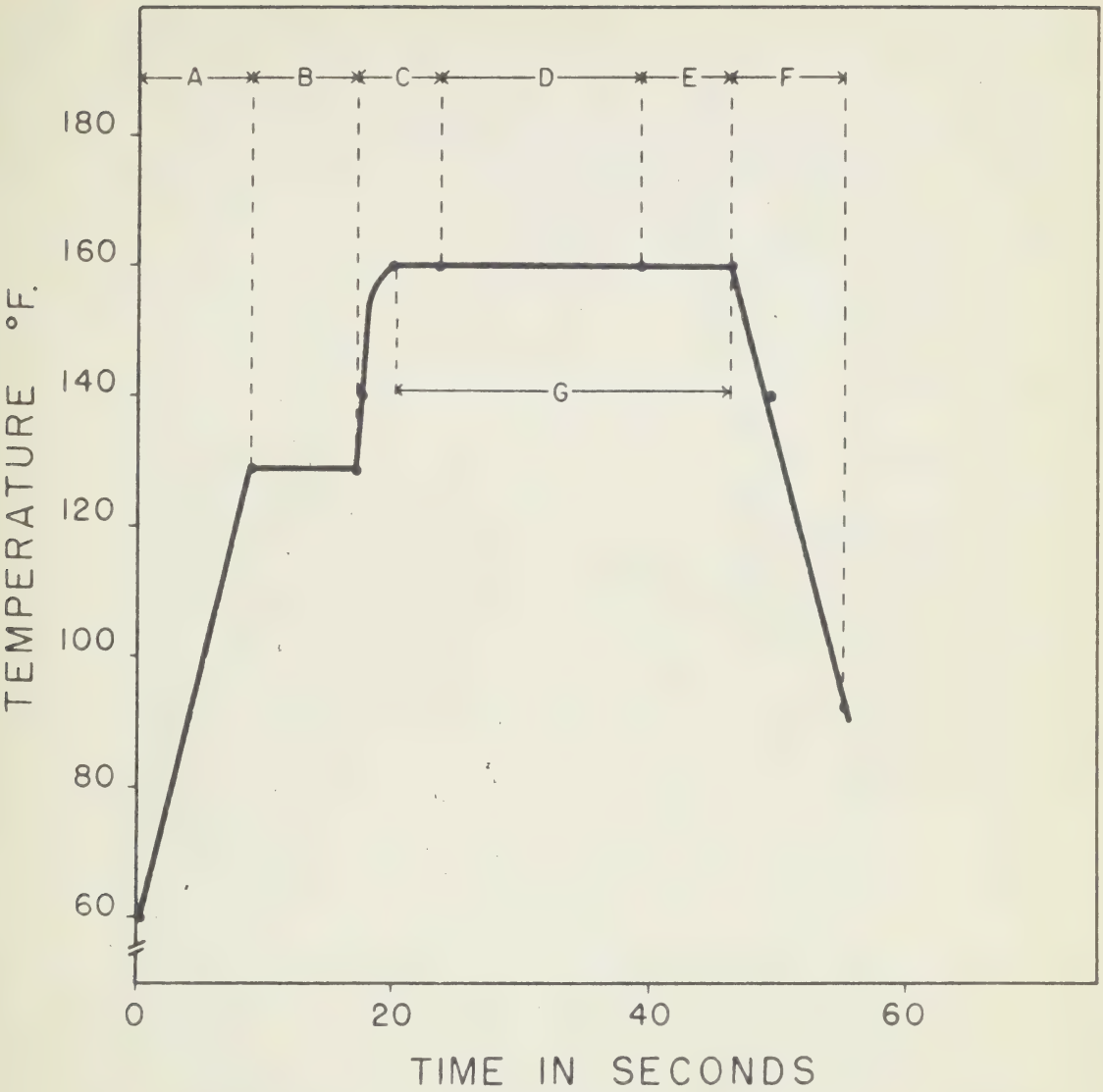

Figure 5

Temperature time curve with plate arrangement A

A - Regenerative section
B - Filter
C - Heater
D - Holder section
E - Post-holder section
F - Regenerative section
G - Control time

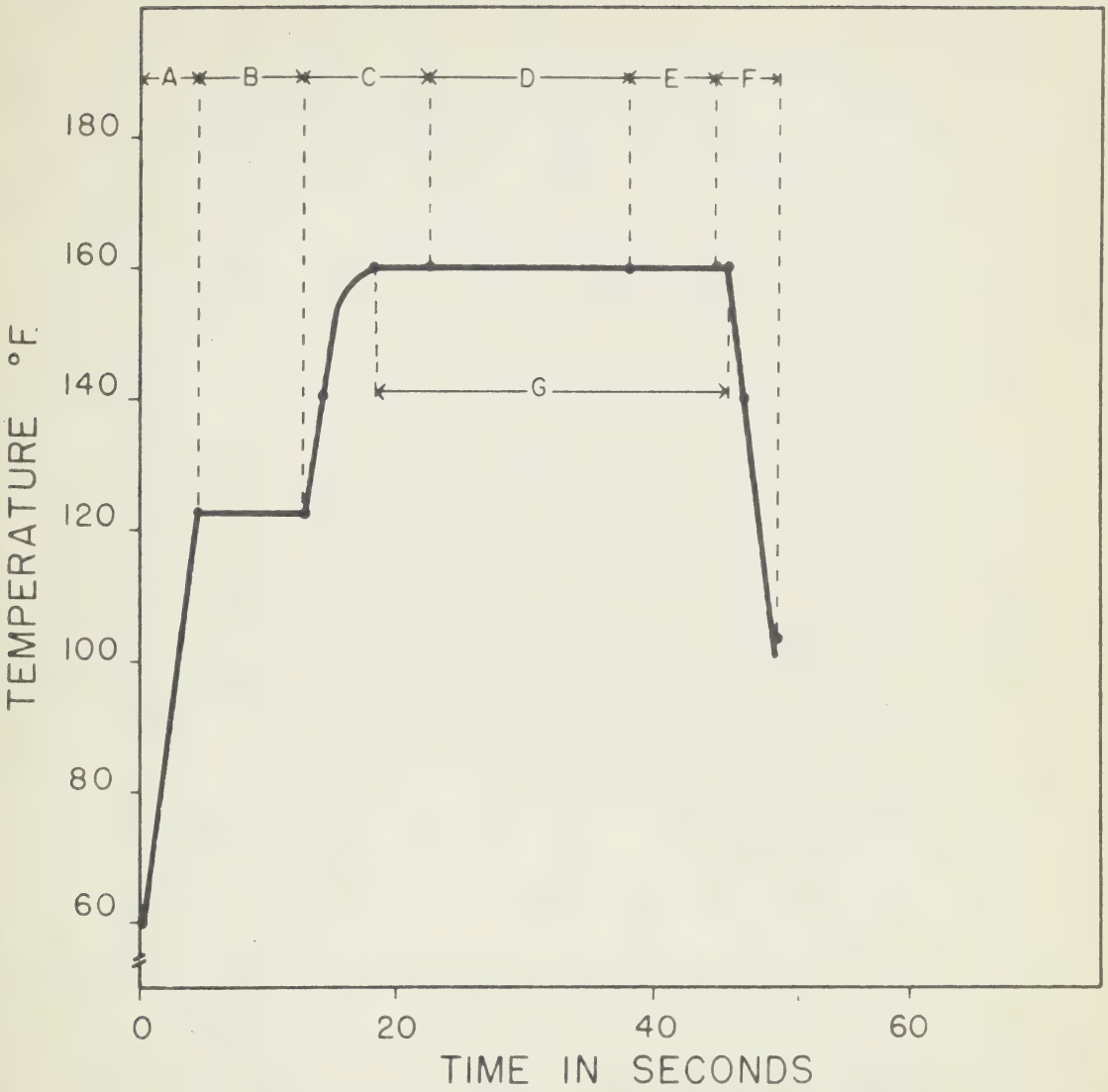

Figure 6

Temperature time curve with plate arrangement B

A - Regenerative section
B - Filter
C - Heater
D - Holder section
E - Post-holder section
F - Regenerative section
G - Control time

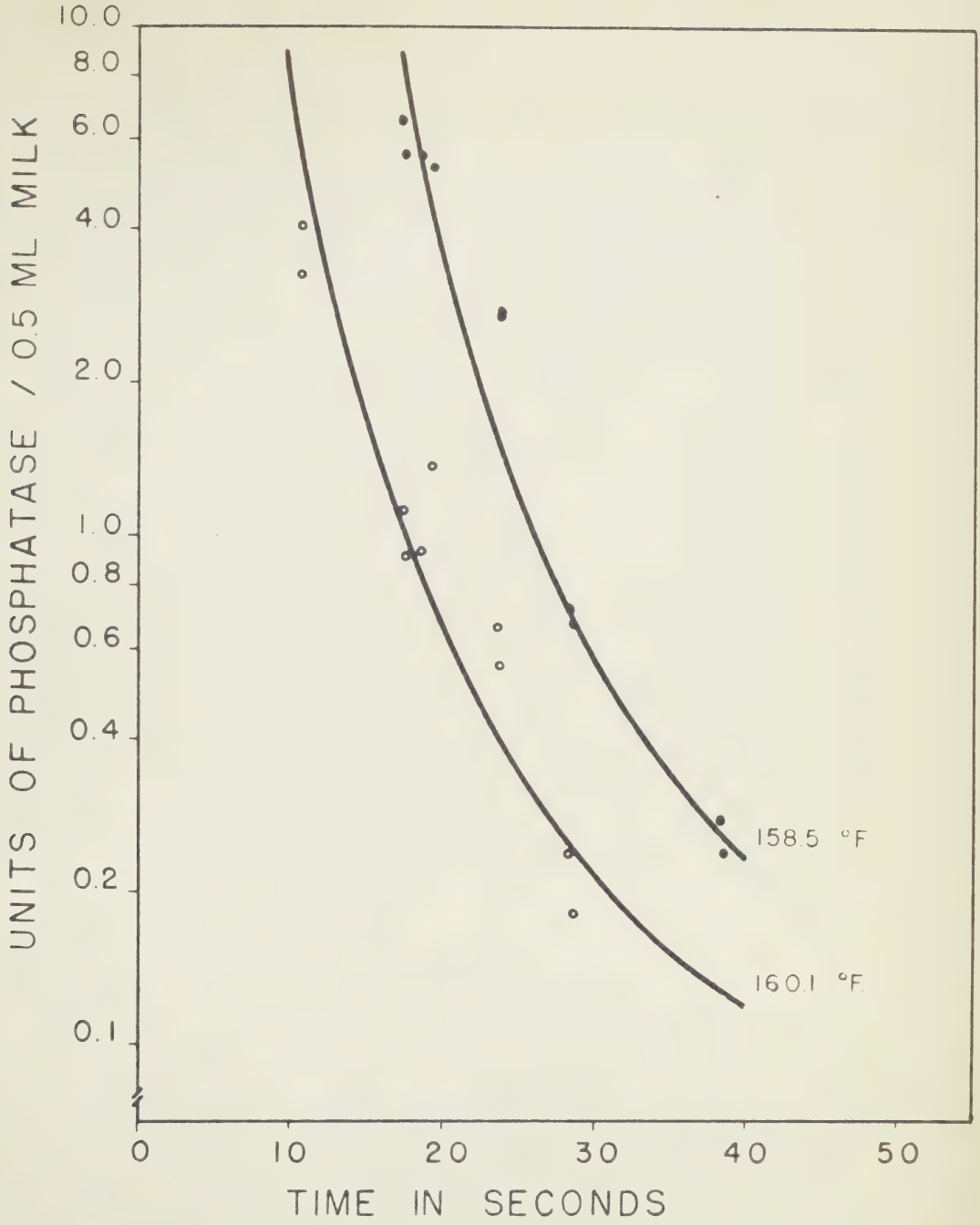

Figure 7

Varying phosphatase destruction with time - plate arrangement B

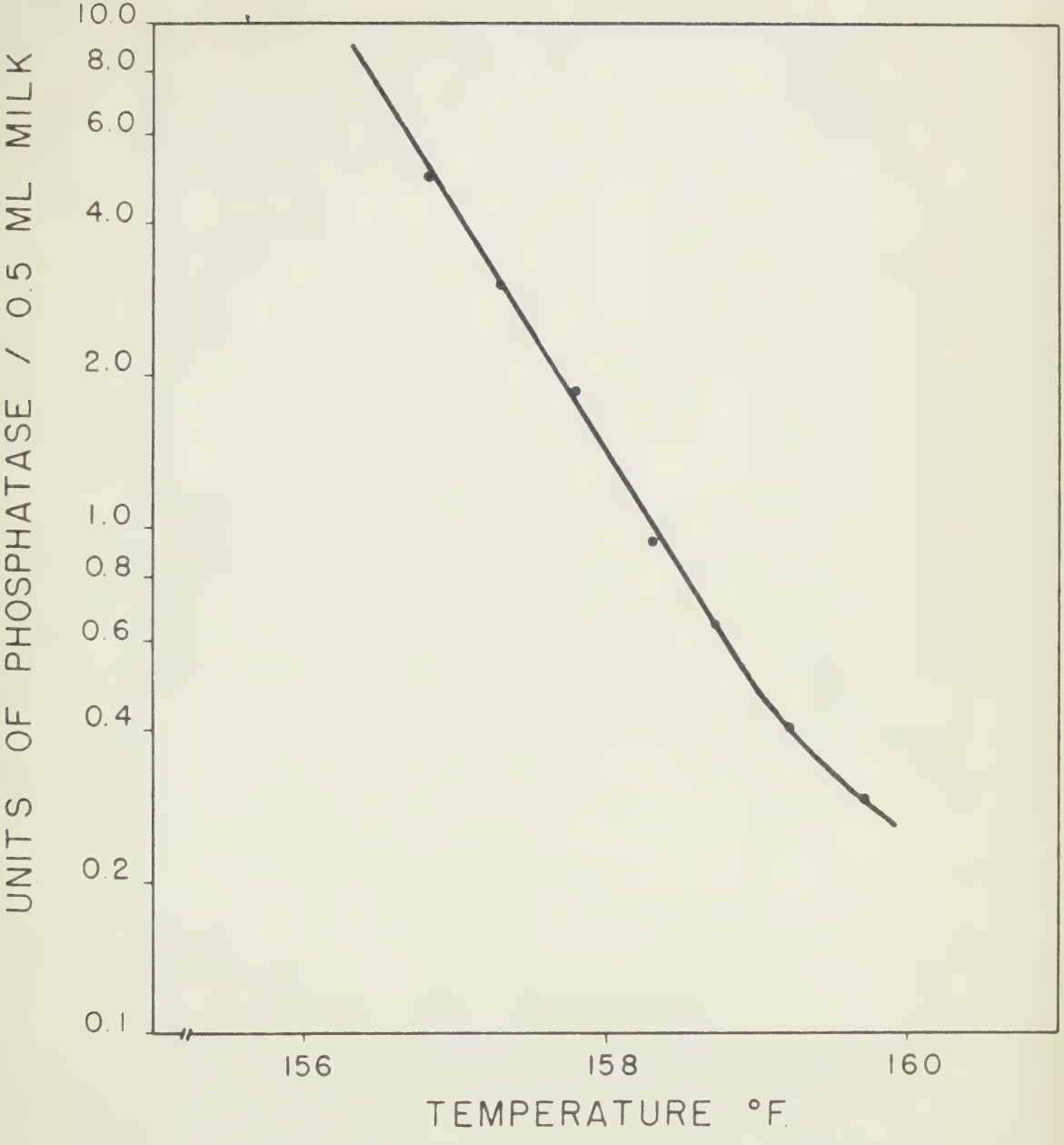

Figure 8

Varying phosphatase destruction with temperature - plate arrangement A

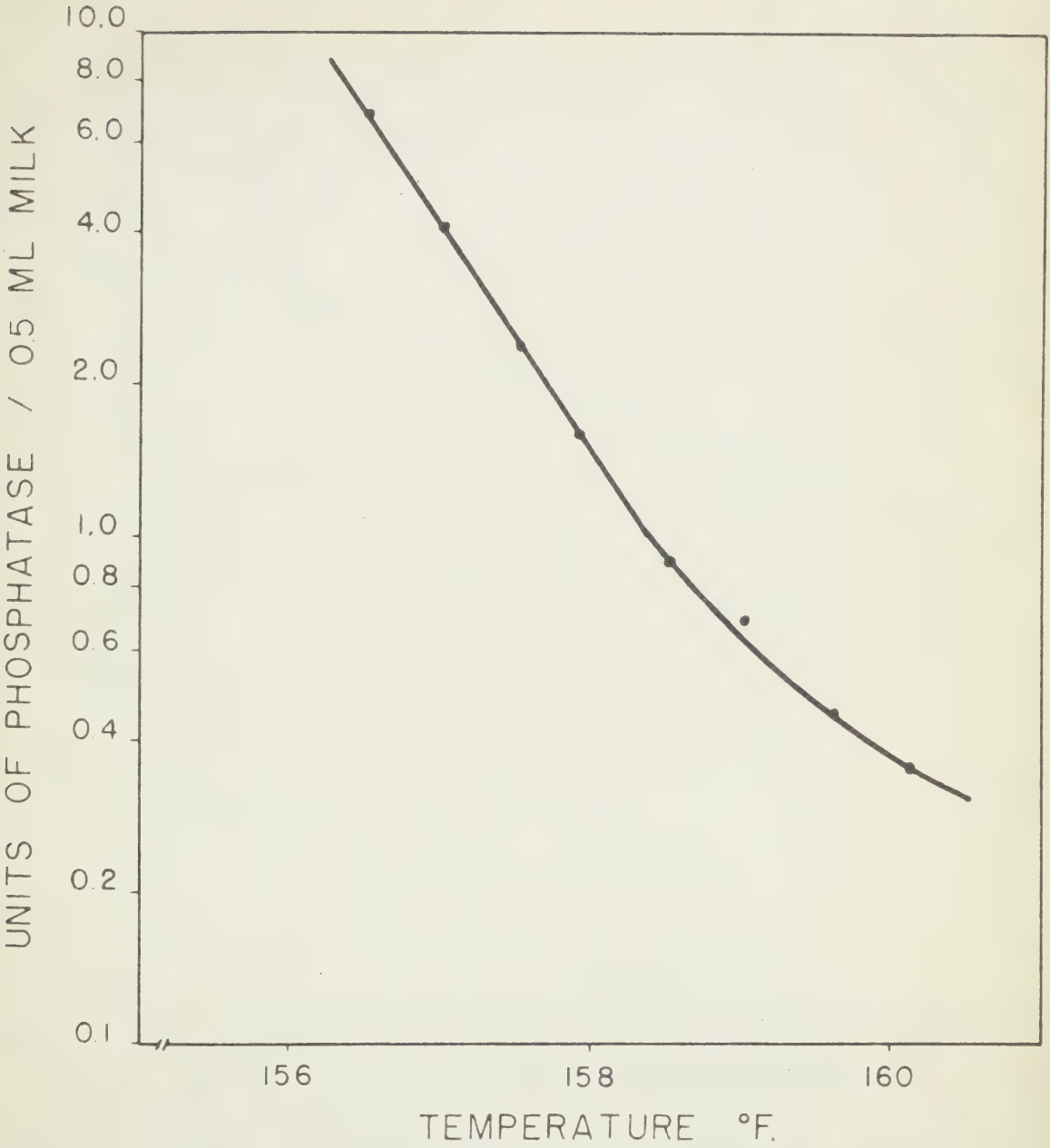

Figure 9

Varying phosphatase destruction with temperature - plate arrangement B

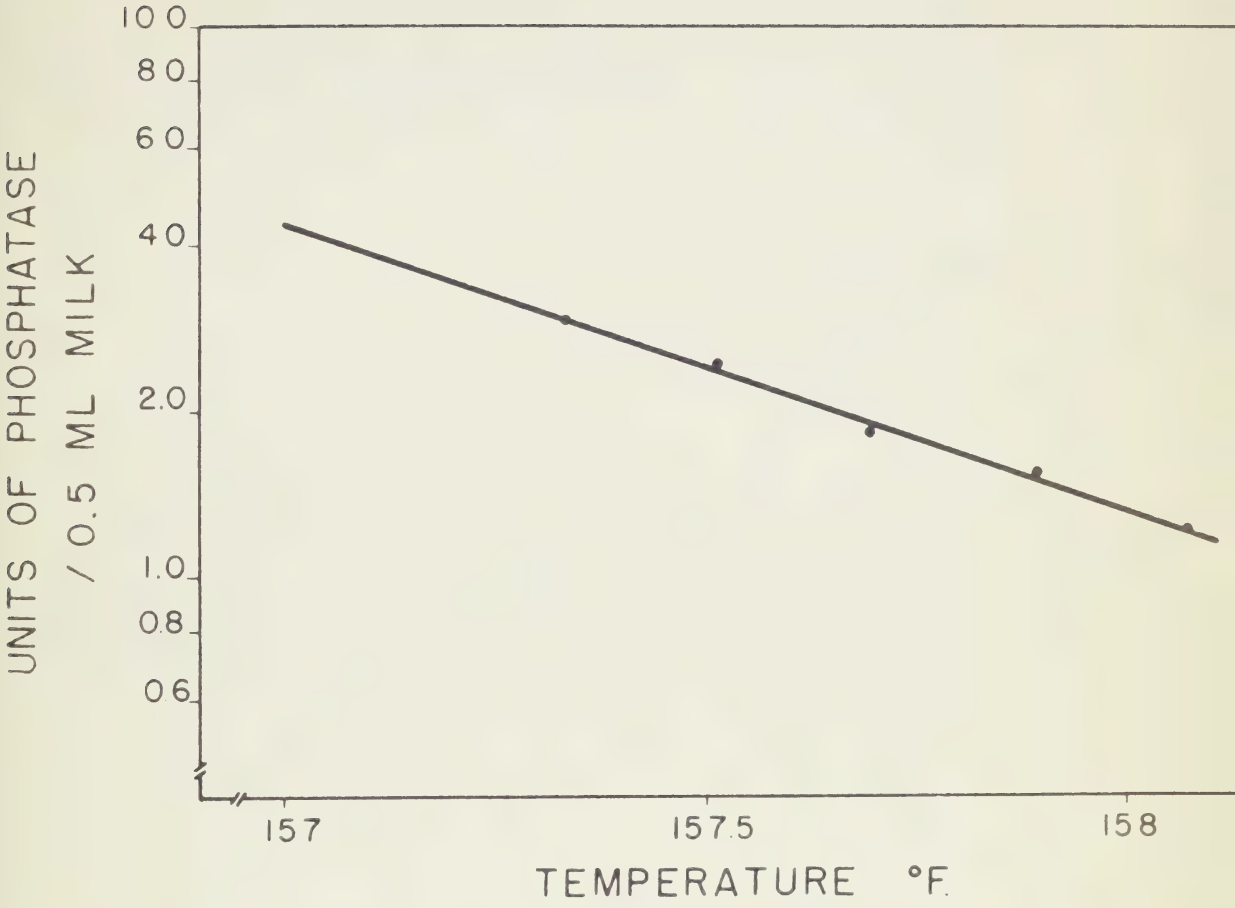

Figure 10

Varying phosphatase destruction with temperature (narrow range) - plate arrangement A

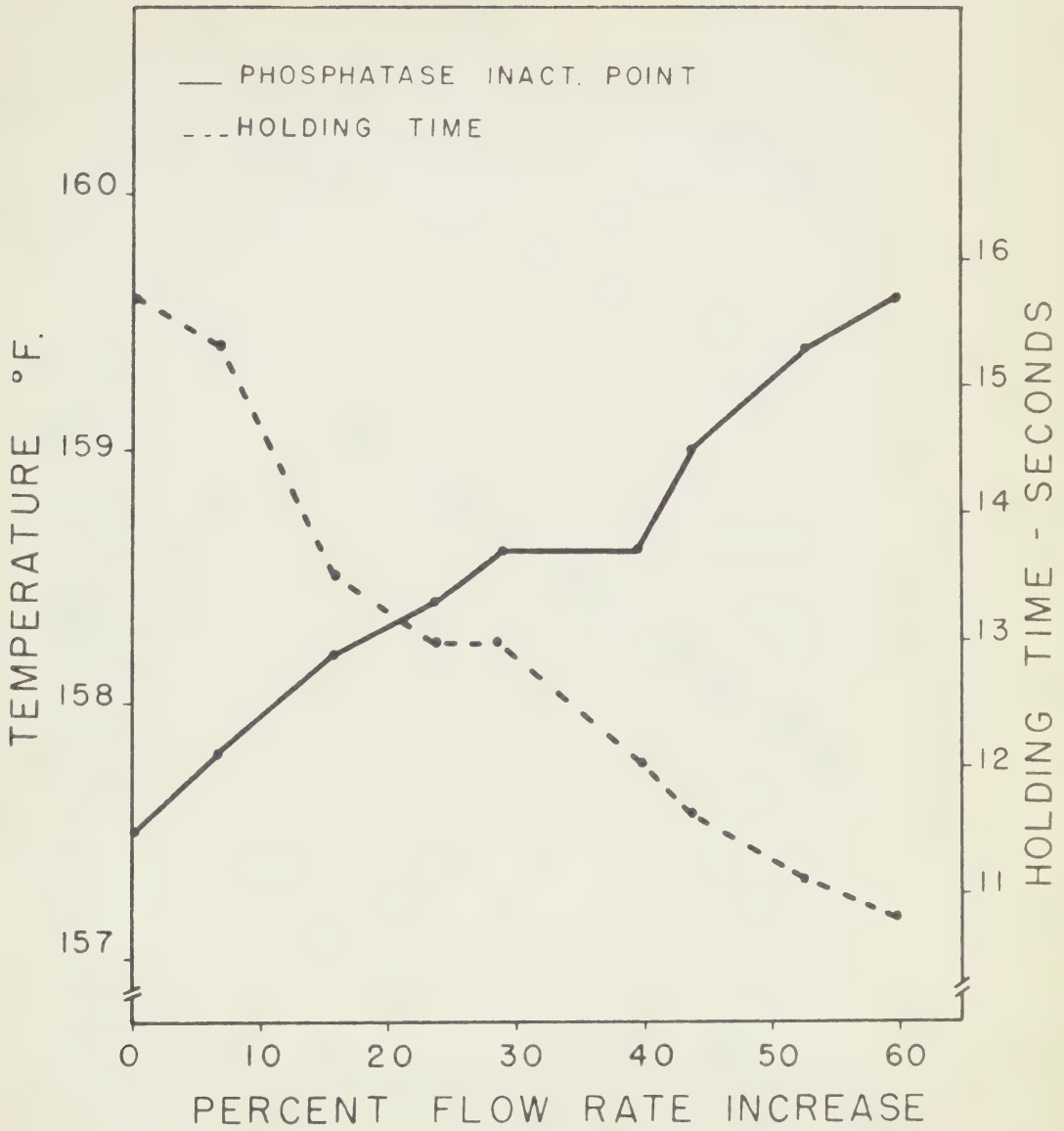

Figure 11

Flow rate increase and phosphatase inactivation

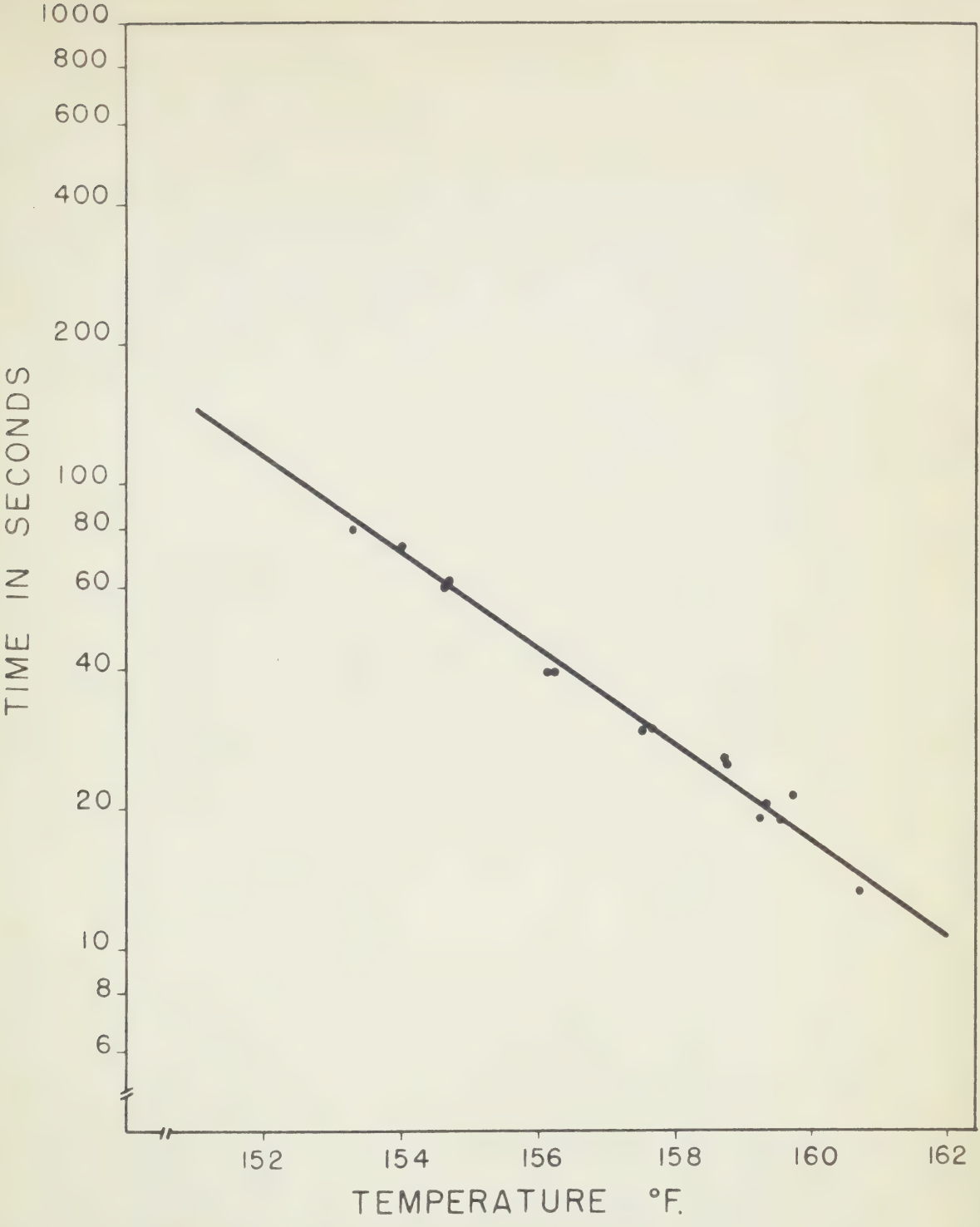

Figure 12

Phosphatase inactivation curve

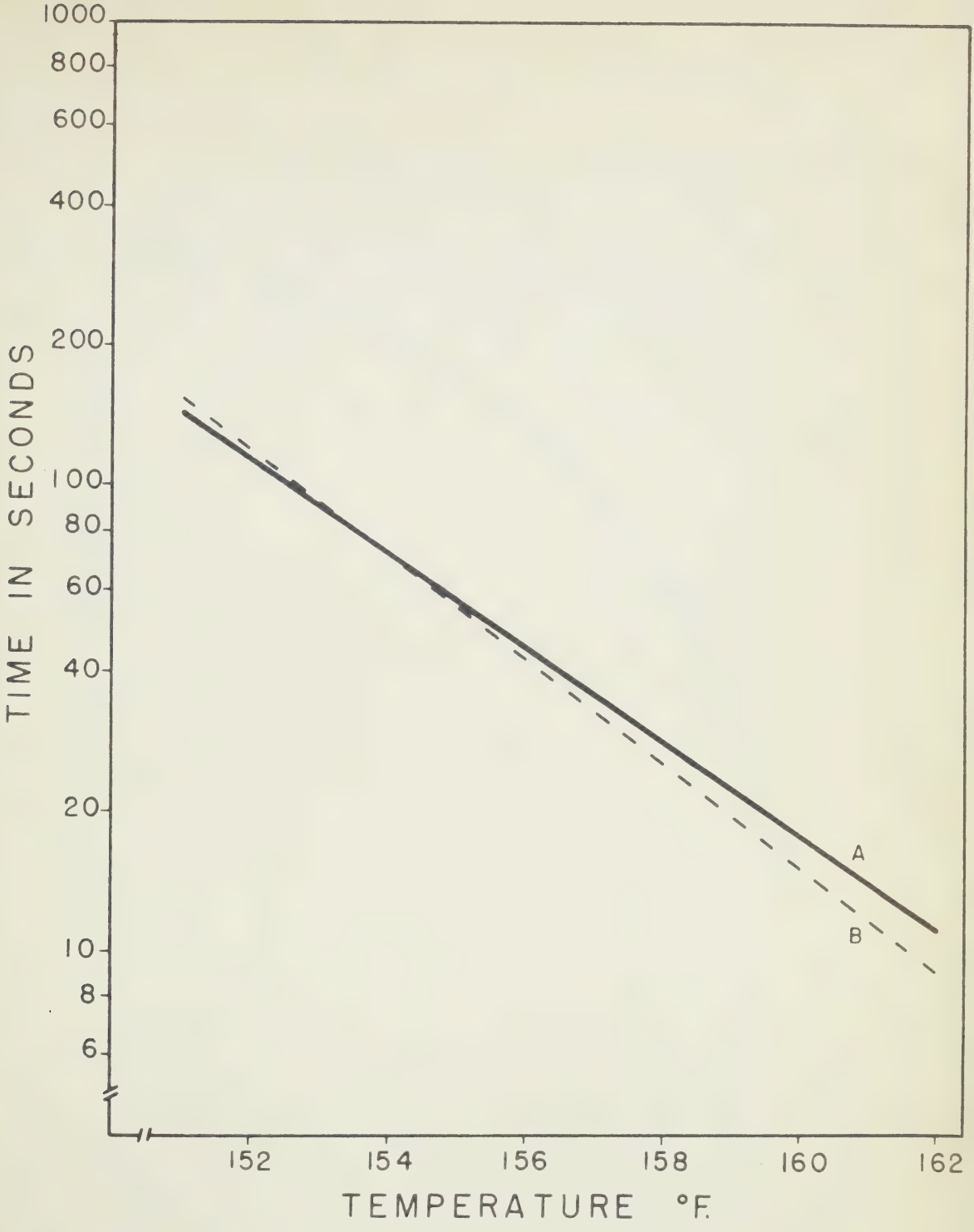

Figure 13

Phosphatase inactivation curves

A - Heating and cooling effect included

B - Heating and cooling effect excluded

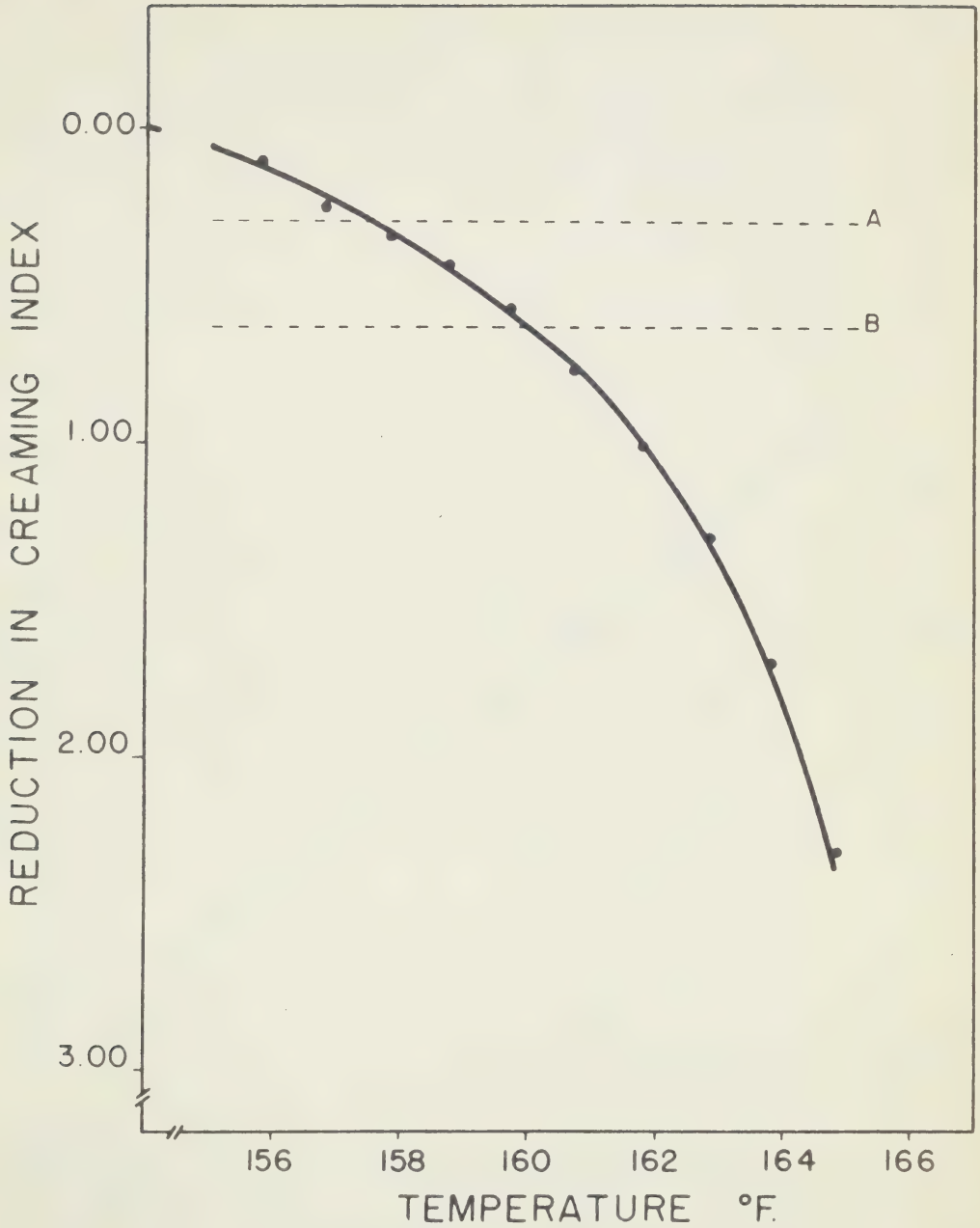

Figure 14

Creaming index curve (arithmetic coordinates)

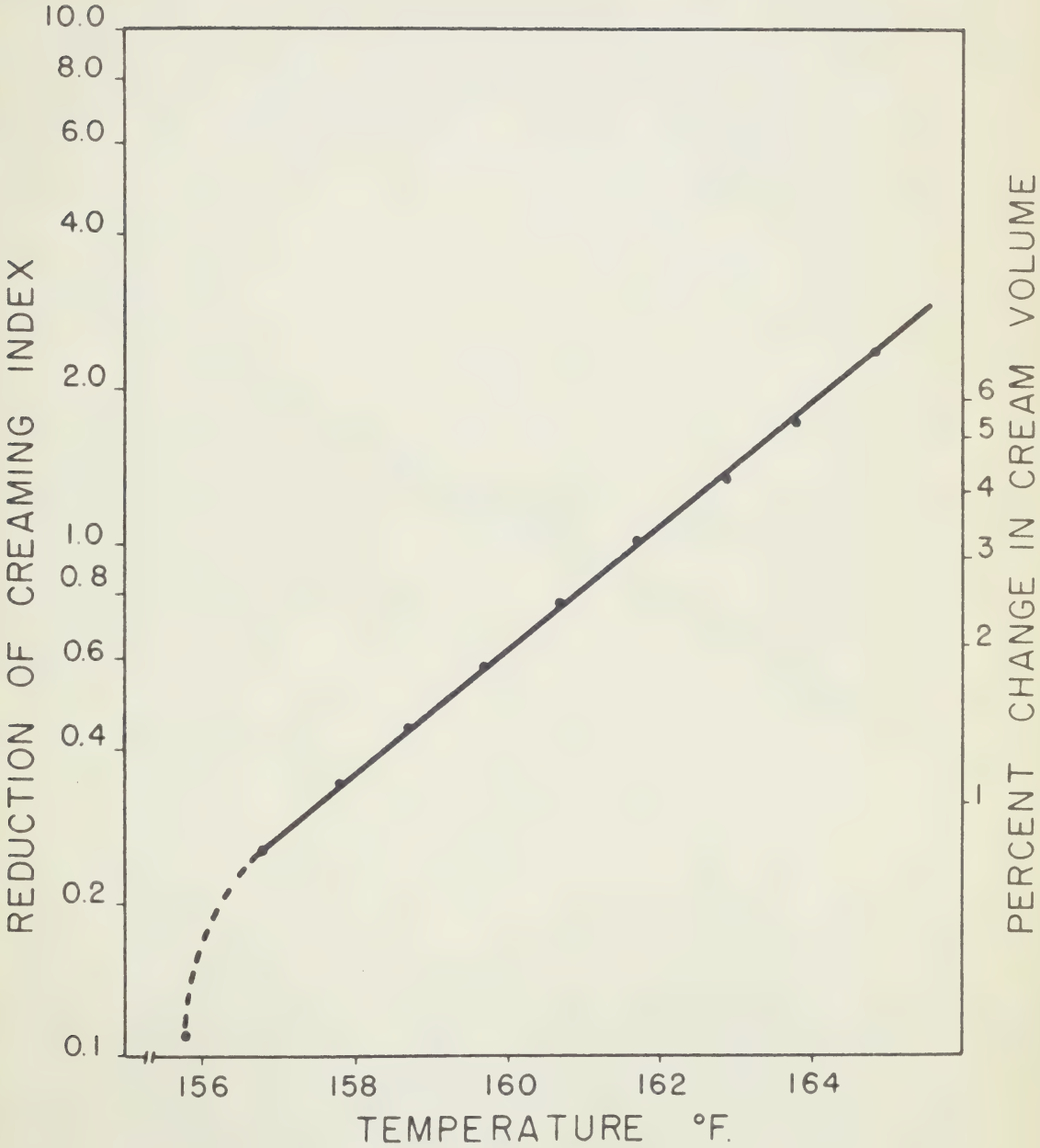

Figure 15

Creaming index curve

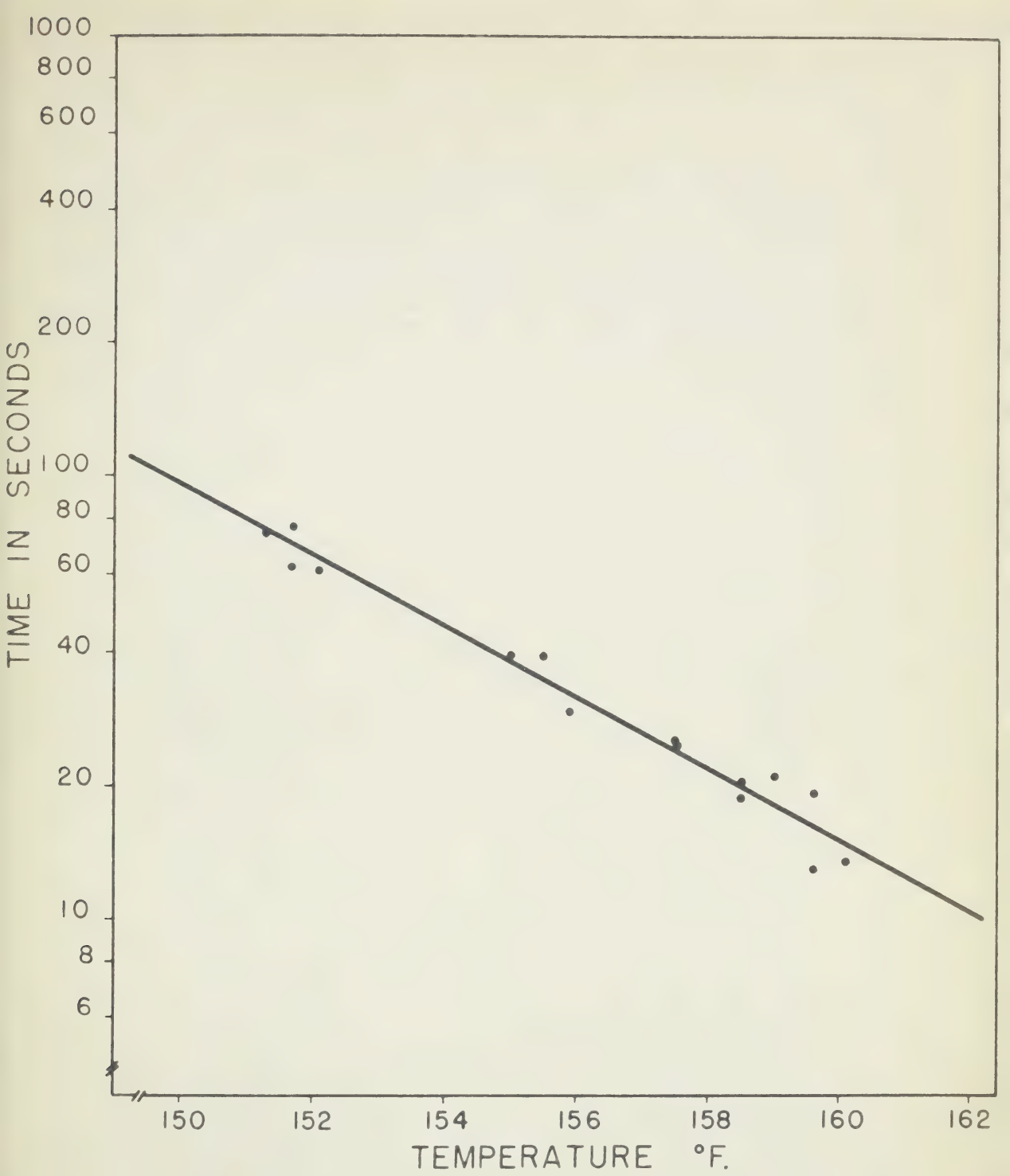

Figure 16

Cream volume curve

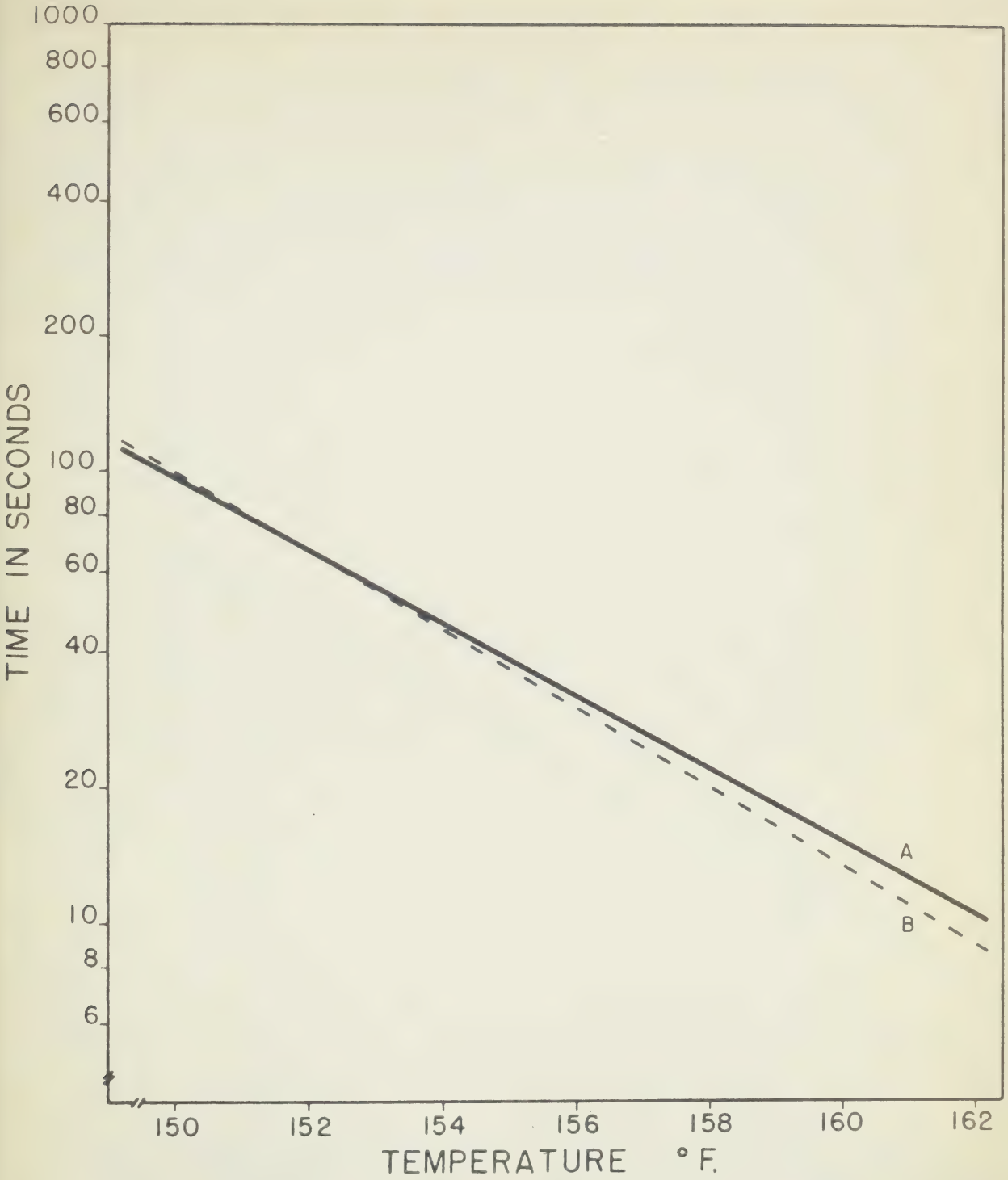

Figure 17

Cream volume curves

A - Heating and cooling effect included

B - Heating and cooling effect excluded

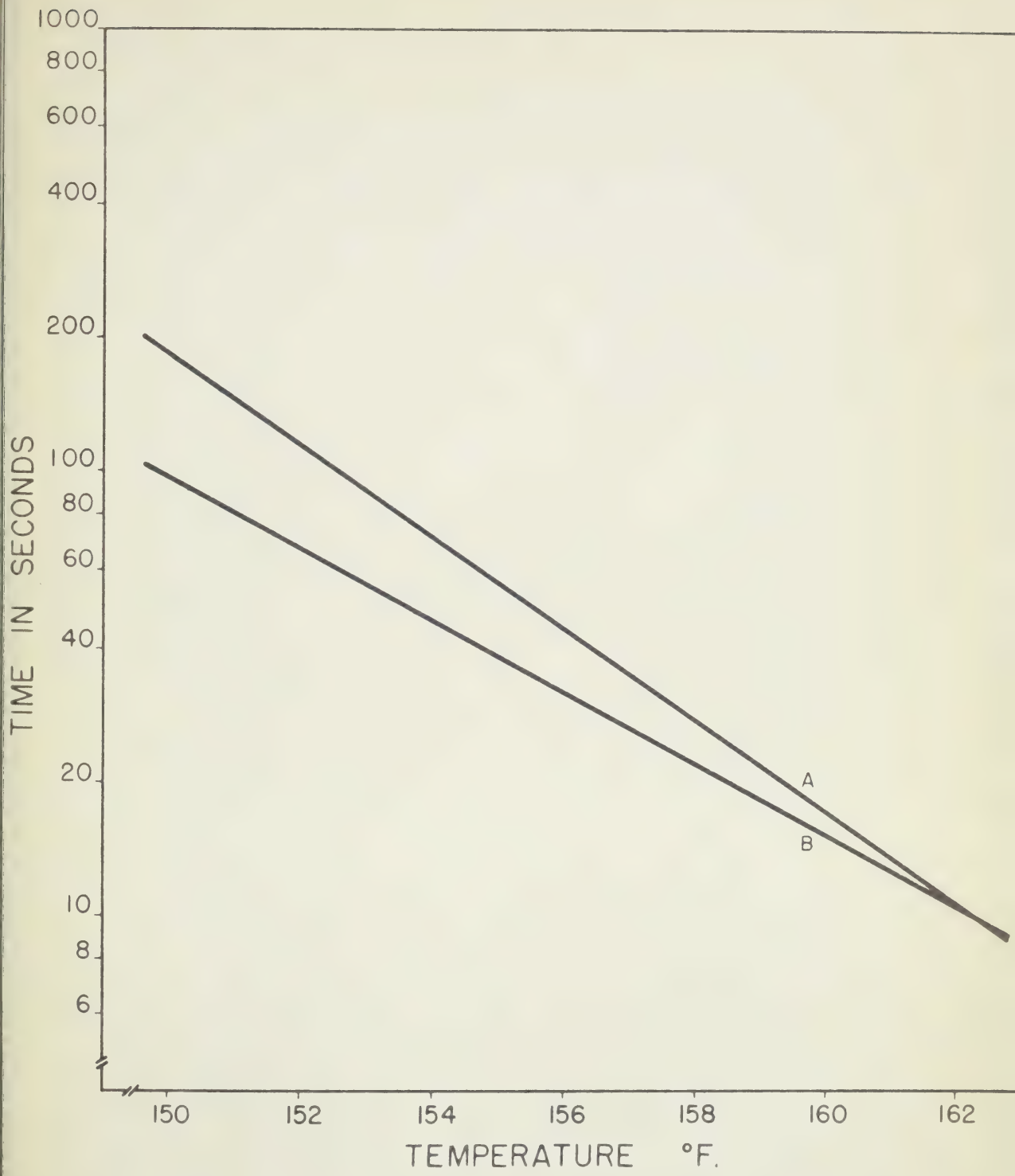

Figure 18

Phosphatase inactivation and cream volume curves

A - Phosphatase B - Cream volume